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FIRES IN STEAMSHIP BUNKER AND CARGO COAL

BY

H. H. STOEK

WASHINGTON
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PREFACE.

The obvious necessity for advancing our knowledge of all conditions met in storing coal, particularly those causing spontaneous combustion and its attendant dangers and losses, has made coal storage a matter of great and timely importance in the work of the Bureau of Mines. A number of studies of various phases of the subject have been made in connection with a general survey of the coal industry. A general restudy and investigation of storage was proposed and outlined to the director, by F. R. Wadleigh, the commercial engineer of the Bureau of Mines and chief of the coal division, Department of Commerce, now assistant Federal fuel distributor; with the director's approval and that of the Secretary of Commerce, the investigation and collection of data were begun early in 1922, by Mr. Wadleigh.

Work on the tabulation of data and compiling the reports was held up, however, by conditions in the coal industry, and, in order to avoid further delay, it was thought advisable to turn over the data to H. H. Stoek, of the University of Illinois, consulting engineer of the bureau, and to issue, as a first installment, a report on fires in ship bunker and cargo coal. This phase of the subject had become of immediate interest owing to fires and explosions on boats running into American ports. J. W. Paul, chief coal mining engineer of the bureau, joined Mr. Stoek in the study of the explosion on the *Adriatic*.

The report has been prepared by Mr. Stoek, and will, it is hoped, be of especial value to steamship owners and to shippers and buyers of water-borne coal. Reports on other phases of coal storage are to be prepared.

I take this opportunity to express my appreciation and thanks to Mr. Stoek for the exceedingly able way in which he has handled the subject, and for his interest in furthering the work of the bureau.

H. Foster Bain, *Director.*

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FIRES IN STEAMSHIP BUNKER AND CARGO COAL.

By H. H. Stoele.

INTRODUCTION.

The opinion is general among marine people in the United States that the number of fires in cargo and bunker coal has greatly decreased during the past 20 years. The replacement in great part of wooden vessels by those of steel and the quicker voyages in steam vessels and by shorter routes would seem to have removed conditions favorable to fires in coal stored on shipboard. However, this opinion is not based on statistics as to the number of fires on American ships due to bunker or cargo coal and the losses to ships and cargoes, and English statistics show the opposite to be true. On November 4, 1921, Sir W. S. Abell, in a paper before the North East Coast Institute of Engineers and Shipbuilders, at Newcastle on Tyne, gave a table of fires due to spontaneous combustion on British ships from 1890 to 1913. This showed that casualties had decreased for nearly all other causes, but had increased strikingly for spontaneous combustion. During the earlier years of this period, spontaneous combustion was frequently included under the general head of "fires," and the figures after 1897 indicate a better segregation under the head of "spontaneous combustion."

Table 1.—*Casualties from fires on British ships from 1890 to 1913.*

Year.	Total ships.	Total casualties.	Fires not caused by spontaneous combustion.	Fires caused by spontaneous combustion.	Year.	Total ships.	Total casualties.	Fires not caused by spontaneous combustion.	Fires caused by spontaneous combustion.
1890–91	3,601	1,705	41	9	1902	3,679	1,675	50	34
1891–92	3,632	1,922	42	8	1903	3,770	1,618	46	47
1892–93	3,577	1,602	29	3	1904	3,890	1,653	60	38
1893–94	3,569	1,781	22	9	1905	3,947	1,734	45	53
1894–95	3,601	2,022	35	2	1906	4,044	1,806	62	65
1895	3,661	1,929	40	9	1907	4,105	1,779	56	97
1896	3,701	2,285	35	11	1908	4,642	1,642	51	90
1897	3,619	2,020	45	13	1909	3,960	1,695	39	99
1898	3,677	2,265	47	24	1910	4,018	1,561	36	72
1899	3,665	1,595	35	29	1911	4,102	1,500	51	98
1900	3,643	1,579	37	36	1912–13	4,062	1,463	39	86
1901	3,656	1,437	34	53					

In the absence of data upon the causes of fires on American ships, reference can be made only to fires from all causes.

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S. D. McComb says:[1]

Few persons realize the appalling extent of the fire damage to shipping annually, as there are no statistics published showing the monetary loss, and only incomplete and inaccurate reports by the Government and by the different classification registers showing the number of vessels and the tonnage loss. However, many lives and millions of dollars in property are lost in flames every year. With a little precaution most of this loss could have been avoided.

In the discussion of a paper on "Safety of life from fire at sea," by W. A. Teague, Stevenson Taylor[2] said:

In 1908, 1909, and 1910, 227 lives were lost in New York City by fires, while for the same period on board all vessels inspected in the United States there were lost by fires 7 passengers, 43 of crew, a total of 50. In New York City there were 5,000,000 inhabitants, or for three years 15,000,000. During the same period the vessels of the United States carried 1,009,000,000 passengers, not counting crews or the millions carried by ferry and excursion boats. That is, 15 per million were lost by fires in New York City and only 0.0033 per million on vessels.

DATA ON SHIP FIRES.

From 1906 to 1910, according to the United States Bureau of Navigation, 317 United States vessels were destroyed by fire and 104 lives were lost. The number of lives lost is only given for vessels totally destroyed, whereas the loss of life on vessels partly destroyed was probably equally large. These statistics show that the average number of American steamers totally destroyed by fire each year is over 60. In addition, about 140 vessels of miscellaneous types are destroyed, a total of 200 per year.

A paper by F. S. Titsworth[3] contains a summary of total losses and fire losses to ships from December 31, 1911, to June 30, 1920, as follows:

TABLE 2.—*Summary of total losses and fire losses to ships, December 31, 1911–June 30, 1920.*

Date.	Total property lost.	Property lost by fire.	Per cent.	Date.	Total property lost.	Property lost by fire.	Per cent.
Dec. 31, 1911.....	$5,235,185	$1,018,322	19.45	June 30, 1917.....	$25,937,365	$1,804,586	6.96
June 30, 1912 [a]....	2,176,863	448,850	20.62	June 30, 1918.....	45,575,812	4,308,014	9.45
June 30, 1913.....	5,710,097	708,617	12.40	June 30, 1919.....	35,109,626	5,399,374	15.38
June 30, 1914.....	8,462,934	977,719	11,55	June 30, 1920.....	26,251,318	3,610,647	13.75
June 30, 1915.....	8,686,742	1,687,283	19.42				
June 30, 1916.....	8,070,336	822,620	10,19	Total, 9½ years..	171,216,278	20,786,032	12.14

[a] Period of 6 months only.

[1] McComb, S. D., Some suggestions for reducing the loss by fire on vessels: Trans. Soc. Naval Arch. and Marine Eng., vol. 18, 1910, p. 191.

[2] Teague, W. A., Safety of life from fire at sea: Trans. Soc. Naval Arch. and Marine Eng., vol. 22, 1914, p. 31; discussion by Stevenson Taylor, p. 53.

[3] Titsworth, F. S., Some statistics with reference to marine fire hazard: Safety Engineering, April, 1921, 8 pp.

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The portion of these totals attributable to coal fires has not been ascertained and is probably not very great, but the losses as listed do not include those due to delays in sailing incident to the heating of coal cargoes or to the cost of removing cargoes that have heated. In New York Harbor, coal that has heated to 120 degrees is frequently refused for bunker and cargo purposes and has to be disposed of otherwise. Within the last few years, coal handlers in several South American ports have required extra pay for handling coal that has heated.

Scant information regarding coal fires on vessels can be obtained from vessel owners, marine agents, insurance and cargo adjusters and surveyors, and coal shippers. A number of sea captains, ship surveyors, and others have been interviewed in connection with the present investigation, and a characteristic answer was that of a former sea captain of long experience in many parts of the world and at present an insurance surveyor and adjuster. He said that in all of his experience he has known only one coal-cargo fire; that occurred when coal being taken from South America to San Francisco caught fire and finally blew up just as the ship was casting anchor in San Francisco Harbor.

Interviews with many persons connected with all phases of handling coal from cars on docks into ships, and with shipowners, insurance agents, and surveyors, have usually resulted in such answers as "No trouble whatever on our ships or with our coal" or "We have no data." However, soon after being thus assured, the writer took passage on a coastwise steamer that makes a round trip of only about 400 miles, and found from the engineer and another official of the boat that recently they had had to put out a fire in the bunker coal of that particular ship. Although this fire was not serious and probably did not endanger the ship, the circumstance indicates that all fires on shipboard are not reported to the ship officials on land.

There may be some disinclination to give out information that might prejudice the traveling public or influence insurance rates, and it is undoubtedly true that data are meager upon what happens to American coal after it has been put on American ships.

J. S. Burrows, of Castner, Curran & Bullitt, who supply large amounts of bunker coal to vessels sailing for the Atlantic seaboard, says in a private communication to the author:

> I believe that there are a great many bunker fires which are never reported and absolutely disregarded for the reason that they do not cause any material damage except to the coal itself. I also think that the danger of spontaneous combustion has been greatly minimized through not only the present use of steel steamers instead of sailing vessels as in former days, but also to the speed of steam as compared with sail.

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Although officials of the United States Shipping Board in Washington reported that there had been no trouble from coal fires on any of the ships of the board, one of the marine insurance companies in New York supplied the writer with a list of 17 ships, including Shipping Board vessels, upon which claims had been paid between July 5, 1920, and July 17, 1922:

TABLE 3.—*Fires on United States Shipping Board and other vessels upon which claims were paid between July 5, 1920, and May 18, 1922.*

Vessel.	Date of fire.	Bunker or coal cargo.	Cost of repairs.
	1921.		
1	Jan. 3	Bunker	$158.00
2	Jan. 18	do	209.30
3	Mar. 7-27	do	1,595.00
4	Mar. 20	do	1,740.00
5	May 19	do	2,500.00
6	May 23	do	125.00
7	July 5-12	do	[a] 830.00
8	July 19	do	[b]
9	Sept. 1	do	[b]
10	Sept. 11	do	1,250.00
11	Sept. 16	do	112.00
12	Sept. 22-27	do	175.00
13	Oct. 3	do	150.00
14	Oct. 5	do	4,100.00
15	Dec. 3	Heated coal in bunker	[c]
	1922.		
16	May 18	Galley coal in No. 8 hold	350.00
17	July 17	Bunker	[d]

[a] $280 of this amount represents the cost of replacing coal damaged.
[b] No damage sustained. $1,132 was the value of coal lost through fire.
[c] No repairs necessary.
[d] No report received.

RECENT FIRES IN BUNKER OR CARGO COAL.

STEAMER "AMERICAN."

The steamship *American* sailed from Los Angeles, Calif., for New York on August 14, 1921, via various ports on the west coast of the United States and the Panama Canal; the vessel reached New York October 4, 1921. During the trip a number of fires were found in bunker coal. In New York the damaged coal, amounting to 427 tons, was sold and replaced at prices approved by the underwriter surveyors. The total claim amounted to $939.15, including the cost of replacing the 427 tons damaged or destroyed.

STEAMER "LANSING."

The steamer *Lansing*, a wooden ship, left Norfolk September 1, 1919, with a cargo of American-mined coal, bound for Genoa. Trouble with the boilers necessitated putting in at the Azores and at Gibraltar for repairs; hence the ship did not arrive at Genoa until December 3. Discharge of cargo was delayed and interrupted on account of further boiler and furnace damage, and on December 22

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smoke was discovered issuing from No. 3 hatch. Firemen were summoned and efforts were made to discover the fire while the discharge of cargo was rushed.

On December 24 fire was discovered in the deck and the forward end of the hatch combing in No. 3 lower 'tween decks, starboard side, and was extinguished after several hours. Fire was subsequently discovered in No. 1 'tween decks and lower hold, and was extinguished without difficulty. Damage consisted of the destruction of deck and inner planking, covering boards, and longitudinal beams below and above flooring. The cost of repairing the damage amounted to approximately $1,200.

STEAMER "LYDIA."

The steamer *Lydia* was laid up at the lower yard of the Baltimore Dry Dock & Shipbuilding Co. On March 12, 1922, a light smoke or gas was discovered coming from the fire room, having escaped from the midship coal bunker. All anchor hatches were removed to allow gas to escape. It was impossible on account of the gas to go down into the bunker, and on March 15 the discharge of coal was begun, whereupon fire started in No. 2 hold on account of an overheated bulkhead. This was extinguished in about an hour, but shortly after fire started inside of bunker No. 2 bulkhead, which was likewise extinguished in a short time. The damage consisted of the following:

1. Four plates in Nos. 2 and 3 strake above bilge buckled.
2. Two plates forward of cross bunker in C and D strake buckled.
3. Lower plate of No. 2 hold bulkhead from shell buckled.
4. Lower corner bracket of No. 2 hold bulkhead buckled.
5. One plate from tank top next to shell slightly buckled.
6. One plate of C strake 'tween decks in way of cross bunker buckled.
7. About 800 feet of ceiling in No. 2 hold destroyed.
8. Casing around vent pipes destroyed.
9. Paint work in aft part of bridge house smoke damaged.
10. Bilges fouled with the charred wood and coal.

The cost of the necessary repairs amounted to $6,500.

In addition to this, 235 tons of coal were damaged or destroyed, and an allowance of 50 per cent, or $705, was claimed, although disallowed by the insurance office.

STEAMER "CUBWOOD."

On August 29, 1922, the steamship *Cubwood* burned in Charleston harbor. The vessel was only about 2 years old and had cost over $1,000,000. About 36 tons of soft coal remained in her bunkers from some time previous to August, 1921, when she laid up in Charleston. The source of the coal could not be ascertained, as it was put in by

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the Shipping Board, then owners; but it is stated that it had become thoroughly pulverized and where drippings of rain water through hatches had wet it, a heavy and very hard crust had formed. The man in charge of the vessel stated that he had not observed any heating in the coal, but as he only went to the bunkers occasionally to obtain galley coal, such a condition, if it existed, might have escaped him. The air was free to circulate through the bunkers. When fire was discovered, it had gained so much headway that it was impossible to note the exact location of its origin, but the fact that it was coming from the bunkers and lower fire room of a laid-up and cold vessel would indicate a bunker fire.

EXPLOSION ON STEAMSHIP "ADRIATIC."[4]

One of the most disastrous shipboard explosions ever recorded was that on the steamship *Adriatic* of the White Star Line. The *Adriatic* completed taking on its bunker fuel—Yorkshire run-of-mine coal—at Liverpool, England, August 4, 1922, and sailed for New York, August 5. On account of the shortage of coal in New York, due to the railroad and coal strikes, additional tonnage was taken aboard to permit a return voyage to Liverpool without coaling at New York. The coal bunkers were not of sufficient capacity to hold this extra amount, hence about 500 tons, which had been wet prior to being placed on shipboard, was placed in the hold adjacent to the usual coal bunkers. The hatch immediately over this reserve bunker was closed August 4 with canvas and boards, on which some cargo was placed.

About 1.30 a. m. Friday, August 11, when the steamship was off the coast of New England, an explosion occurred in the coal bunkers marked A and B on the accompanying plan, Figure 1; six members of the crew were killed immediately or died soon after. None of the 600 passengers was injured, and many did not know that an accident had occurred until some time afterward. The ship was not injured structurally, and the damage to the cargo amounted to only about $1,000, according to the estimates of the New York underwriters.

For some distance back from the bulkhead between bunkers *A* and *B* a steel partition divided each side of the bunker *A* into two parts—*a*, *b*, and *a'*, *b'*, section *I–I'* (see fig. 2). The coal from *a* and *a'* had been practically used up and to make the reserve bunker *B* available for the return cargo from New York preparations were made to move the coal from bunker *B* before reaching port in New York. The small door *c* on the port side between bunkers *A* and *B* was opened and had been opened for about half an hour when the ex-

[4] Abstract of a report to the Bureau of Mines, by J. W. Paul and H. H. Stoek.

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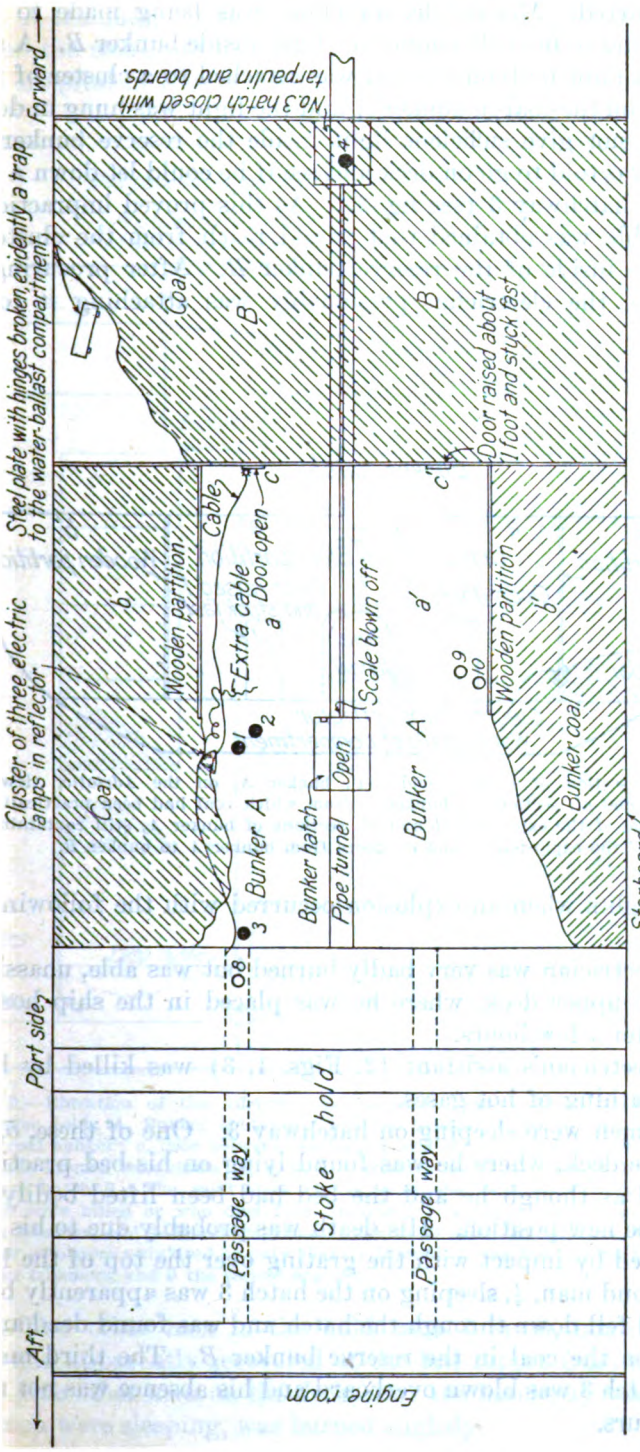

FIGURE 1.—Plan of No. 3 bunker hold of the *Adriatic*: *A*, Bunker containing fuel for boilers; *B*, cargo hold, temporarily used for coal storage; *c* and *c'*, doors between bunkers *A* and *B*. The solid black circles show the location at the time of the explosion of members of the crew who were killed or who died from injuries (1 was the electrician, 2 his assistants, 3 a trimmer, and 4 a fireman). Circles 8–10 (8 and 10 were trimmers, and 9 the second engineer) show the location of members of the crew who were uninjured or only slightly injured.

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plosion occurred. Meanwhile, an effort was being made to open the door *c'* and to provide temporary light inside bunker *B*. A short cable with a light bulb on the end was attached to a cluster of three lights lying on the coal in bunker *A* and the light was hung in door *c*. As this did not give sufficient light inside the reserve bunker, the electrician was told to go on deck and see if he could let down a light through the hatchway 3 (see fig. 3). As this proved impracticable, a longer cable was obtained that would reach from the cluster of lights to the inside of the reserve bunker *B*. After procuring the longer cable, the electrician presumably was attaching it to the

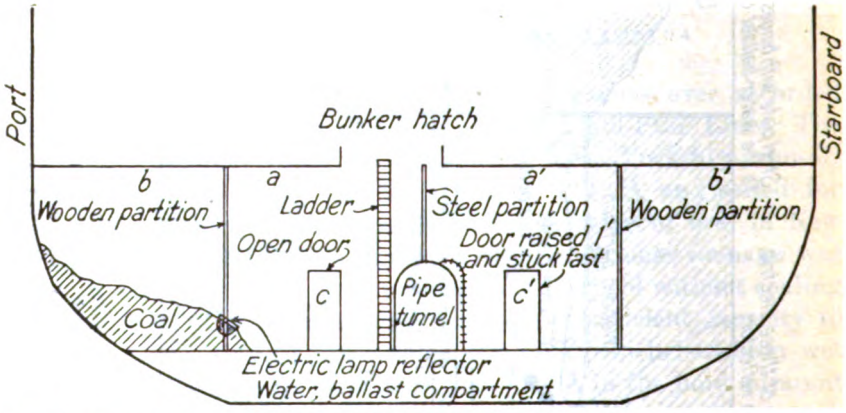

FIG. 2.—Cross section of bunker hold I–I', bunker A, on the *Adriatic*, view from stokehold: *a* and *a'*, sections of bunker A from which coal had been practically used up at the time of the explosion; *b* and *b'*, sections of bunker *A*, still containing coal at the time of the explosion; *c* and *c'*, doors from bunker *A* to bunker *B*.

cluster of lights when an explosion occurred with the following results:

1. The electrician was very badly burned but was able, unassisted, to reach the upper deck, where he was placed in the ship hospital and died after a few hours.

2. The electrician's assistant (*2*, Figs. 1, 3) was killed by burns and the breathing of hot gases.

3. Three men were sleeping on hatchway 3. One of these, *5*, was blown to the deck, where he was found lying on his bed practically undisturbed as though he and the bed had been lifted bodily and placed in the new position. His death was probably due to his head being crushed by impact with the grating over the top of the hatch at *k*. A second man, *4*, sleeping on the hatch 3 was apparently blown upward and fell down through the hatch and was found dead among the débris on the coal in the reserve bunker *B*. The third man, *6*, asleep on hatch 3 was blown overboard and his absence was not noted for some hours.

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4. A trimmer, 3, who was going through or was near the door between the stokehold and the bunker *A*, was badly burned, and died in a hospital in New York City six days after the explosion.

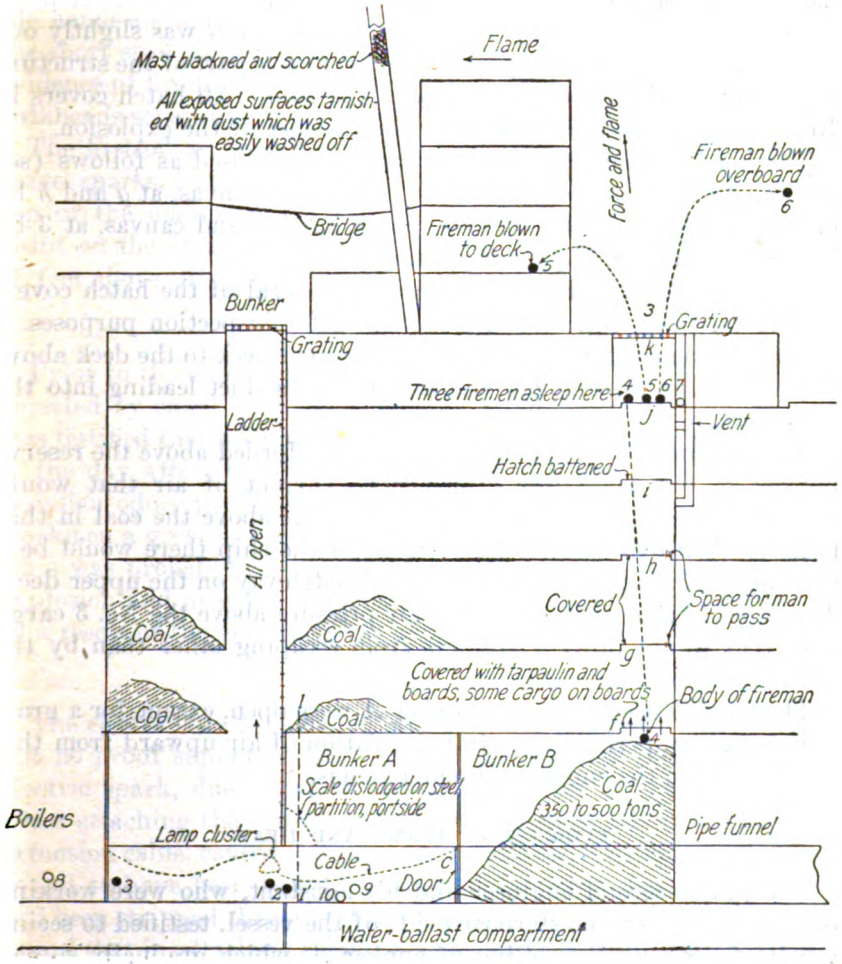

FIG. 3.—Elevation of the *Adriatic*, showing the decks included by No. 3 hatch and bunker hold: *A*, Bunker containing fuel for boilers; *B*, cargo hold, temporarily used as coal bunker; *c*, door between bunkers *A* and *B*; *e*, deck to which the body of one of the firemen was blown; *f*, *g*, *h*, *i*, *j*, hatches above the reserve bunker; *k*, grating above hatch 3. The solid black circles show the location of members of the crew who were killed or who died from injuries; 1 was the electrician, 2 his assistant, 3 a trimmer, and 4–6 firemen; open circles 7–10 show the location of members of the crew who were uninjured or only slightly injured, 7 was the leading fireman, 8 and 10 were trimmers, and 9 the second engineer.

5. Two other men in the hold were injured, but only slightly, and had apparently recovered at the last report from the ship.

6. One other man on the deck, near the hatchway where the three firemen were sleeping, was burned slightly.

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The damage to the ship was very slight and consisted of blackening of the main mast and a small amount of the adjacent woodwork. Some of the steel beams were bent and the boom of the derrick near hatch 3 was bent by being struck by falling hatch beams. A bilge plate in the left aft corner of the reserve bunker *B* was slightly out of place. There was no apparent damage to any part of the structure of the ship and no evidence of fire in the hold. All hatch covers in No. 3 hatchway were blown off by the violence of the explosion.

The hatches above the reserve bunker were closed as follows (see fig. 3): At *f* by loose plank hatches covered by canvas, at *g* and *h* by loose plank hatches, at *i* by loose plank hatches and canvas, at 3 by loose plank, and at *j* by hatch grating.

Small openings had been left through several of the hatch coverings to facilitate entrance into the decks for inspection purposes.

An open ventilator extended from the upper deck to the deck above hatch *i* and an electric fan was attached to a duct leading into the same deck.

A small amount of ventilation was thus afforded above the reserve bunker *B*, but there was probably no current of air that would effectively clear out any accumulation of gas above the coal in that bunker. With the forward movement of the ship there would be a current of air deflected down the No. 3 hatchway on the upper deck. This would bring about a certain air pressure above the No. 3 cargo hold that would prevent any gas from escaping other than by the law of diffusion.

The hatches above the coal bunker *A* were open, except for a grating at the top, permitting a full circulation of air upward from this hold and from the engine and boiler rooms.

EVIDENCE OF FLAME AND HEAT.

The junior second engineer and his assistant, who were working to open door *c'* on the starboard side of the vessel, testified to seeing a ball of fire near the ceiling of bunker *A*, which gradually spread into a broad flame extending across the ceiling of the bunker. These men were not burned or otherwise injured. The air was filled with dense black smoke and they could not see, but found their way to the stokehold.

Firemen and coal passers working in the boiler room testified to seeing a light in the passage from the bunker and between the boilers, but it was not clearly shown whether they saw actual flame or the reflection of light from the coal bunker. Some of the same men testified to feeling a blast of hot air passing over them. One man testified that it was cool air. None of them was burned, nor did any testify to feeling any excessive heat from the explosion.

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A canvas jacket on one of the boilers and the canvas covering on the hatch above the reserve bunker caught fire. Loose coal on the floor of bunker *A* fired but was extinguished by a few buckets of water. A small fire in bunker *B* was put out by hose turned down the hatch above *B*. Scale from the surface of the pipe tunnel and the short steel partition in bunker *A* was loosened, but there was no evidence of fire on any of the steelwork in the hold or on the wooden bulkheads separating *a* and *b* or *a'* and *b'*.

The first officer, who was on the bridge of the ship, reported that flame, sparks, and débris were thrown through hatch 3 as high as the top of the mainmast and 50 feet above the bridge. Some of the paint on the bridge was blistered, and the mast was blackened for 15 feet above the pilot cabin.

NATURE OF THE GAS.

Prior to the explosion, there was no evidence of gas that could be detected by smell or eyesight coming from the reserve bunker. It was testified that upon opening the doors between the bunkers *A* and *B* the day after the explosion a strange gas was noted that had a peculiar odor, produced a choking effect on the throat, gave the workmen a great desire to drink water, and made them light-headed. This was probably carbon dioxide confined in the bunker after the explosion and mixed with other coal gases which would be given off as a result of the heat from the explosion.

IGNITION OF THE GAS.

The electrician or his helper was rumored to have struck a match, but no proof supported this. All of the evidence indicates that an electric spark, due either to imperfect contact at the lamp cluster when attaching the extension cable or to a short circuit in the short extension cable, caused the explosion. The short extension cable was found to have been badly burned and for some distance the wires had been stripped through burning of the insulation. Mr. Paul also found that in attaching the longer cable to the lamp cluster, a spark was given off. It was also reported that at about the time of the explosion, a fuse was blown on the line to which the lamp connections were attached, but there was no evidence as to just when this occurred.

CHARACTER OF COAL.

The Yorkshire coal (probably from the Carlton main colliery) was loaded at Liverpool on Friday, August 4. The coal was damp when loaded and when examined by the writers August 14 the coal in the reserve bunker was cool and damp on the surface and when thrown into the air gave no evidence of being dusty. A similar

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condition prevailed later in the day when the coal was being shoveled out of the bunker hold.

The ship's officers testified that coal had been carried in the same hold previously for a period of three months without being moved and with no bad results. The previous cargo in the reserve bunker had been corn, of which a few grains were found. The chief engineer and the captain stated that the coal was evidently high in volatile, as evidenced by large volumes of smoke when fired. Tests and analyses of coal sent to Pittsburgh gave results shown below.

The sample of coal taken from the No. 3 cargo hold and shipped in a strong wooden box was received at the Pittsburgh experiment station on August 18. The box was immediately opened and 50 lbs. of the coal placed in a tin receptacle and made air tight. On August 23 a sample of the gases in the container was taken for analysis, and on September 22 a second sample was taken. The analyses of the two samples are as follows:

Analyses of gas from coal from No. 3 hold.

Sample taken	Aug. 23	Sept. 22
Laboratory No	17180	17355
Carbon dioxide (CO_2), per cent	2.0	3.1
Unsaturated hydrocarbons (C_2H_4 etc.), per cent	.1	.0
Oxygen (O_2) per cent	6.9	.2
Hydrogen (H_2), per cent	.2	.1
Carbon monoxide (CO), per cent	.0	.0
Methane (CH_4), per cent	12.0	39.2
Ethane (C_2H_6), per cent	.0	.9
Nitrogen (N_2), per cent	78.8	56.6
	100.0	100.0

An analysis of the coal is as follows:

Air-dry loss, 2.0	Air dried.	As received.	Moisture free.	Moisture and ash free.
Proximate analysis.				
Moisture	2.0	3.9	.....	.....
Volatile matter	33.8	33.1	34.5	36.4
Fixed carbon	59.0	57.9	60.2	63.6
Ash	5.2	5.1	5.3	.....
	100.0	100.0	100.0	100.0
Ultimate analysis.				
Hydrogen	5.3	5.4	5.2	5.5
Carbon	78.5	77.0	80.1	84.6
Nitrogen	1.6	1.6	1.6	1.7
Oxygen	8.6	10.1	7.0	7.4
Sulphur	.8	.8	.8	.8
Ash	5.2	5.1	5.3	.....
	100.0	100.0	100.0	100.0
Calorific value.				
Calories	7,700	7,550	7,856	8,300
B.t.u.	13,860	13,590	14,140	14,940

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CONCLUSIONS.

It seems probable from the evidence at hand that the explosion was due: (1) To an accumulation of gas above the coal in the reserve bunker *B;* and (2) to the ignition of this gas (which moved out into bunker *A* when the bunker was opened) due either to imperfect electric contact at the cluster of lights or to a short circuit in the extension cable. The lighting of a match would have accomplished the same result.

REPORTS ON FIRES.

In July, 1912, a report to Lloyd's Register of Shipping by J. T. Milton,[5] chief engineer surveyor, noted that during 1911, 103 vessels were reported by the Shipping Gazette and Lloyd's as arriving at or being in port with bunkers on fire and 24 vessels with cargoes on fire.

According to a report of the British Board of Trade[6] quoted at length (see pp. 21–22), there were reported on British ships from August 1, 1919, to July 31, 1920, 74 bunker fires, in most of which the damage to the vessel was not serious, but in three instances the vessels were lost. During the same period there were four fires in coal cargoes.

During the 18 months from April 1, 1920, to September 29, 1921, 252 fires in coal, either cargo or bunker, were reported in "Lloyd's List." This figure includes foreign-owned as well as British vessels, and overlaps the records in the Board of Trade report by three months.

Of these 252 fires, 189 occurred in bunkers and 63 in cargoes, one of the latter being reported as an explosion, not as a fire. Ten fires resulted in the total loss of the vessels—seven of these being sailing vessels, two steamers, and one an auxiliary motor vessel.

In 1904, Prof. Richard Threlfall testified before a British commission:[7]

> There have have been enormous numbers of cases of spontaneous combustion in coal coming from England, especially that leaving the Welsh ports. In 1876 I think 4 per cent of the total overseas shipments were heated; * * * it is not as bad as that now. There is an enormous amount of work to be done with regard to it and if done I feel certain there will be no more spontaneous combustion.

There are but a few examples of coal fires upon which it has been possible to secure data. Ship masters are reluctant to report disasters to their vessels, and if they have a fire in a coal cargo, but are

[5] Report by the chief engineer surveyor on fires on board ship, Lloyd's Register of Shipping, London, 1912.

[6] Great Britain Board of Trade, Report on fires which occurred or were reported on British ships during the period, 1st August, 1919, to 31st July, 1920, London, 1921.

[7] Second report of the Royal Commission on Coal Supplies, London, vol. 1, 1904, p. 228, pars. 14107–14108.

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able to make port and discharge the cargo without damage to the vessel, they make no report of it.

Apparently there are very few fires either in bunker or cargo coal on the Great Lakes steamers, although large quantities of coal are carried every year on such vessels. The water of the lakes is cold and the coal is seldom in the bunker or cargo hold for as long as a week. Fires occasionally occur in coal that has been left aboard ship over the winter, but the fire losses from coal have been very small.

In view of the statistics quoted and the meager data available regarding fires from coal on American vessels, some interested agency should obtain more definite information as to the behavior of American coals after being placed on shipboard.

In a report of the United States Navy,[8] dated January 27, 1898, and quoted at length later (see pp. 16–20), it was stated:

> No experiments to determine beyond question the exciting causes of bunker fires have been made. The researches of the eminent chemists already mentioned and a study of the conditions where bunker fires have occurred enable conclusions to be drawn that we believe correct, and upon these conclusions our recommendations have been based. The fact remains, however, that the very conditions which seem to have been the cause of a bunker fire on one ship have existed on many others without causing trouble. Apparatus could be built reproducing bunker conditions and every condition supposed to be provocative of spontaneous ignition could be reproduced, carefully tested, and judged. The cost would probably be $5,000.

No such experiments seem to have been made by the Navy or other Government agency, and the same conditions as to lack of accurate data still prevail. If the present paper, by calling the attention of those connected with the shipping industry to this lack of information, leads them to gather data upon the subject that will be helpful, it will have served its purpose.

In an address before the International Conference on Safety of Life at Sea, Inspector General George Uhler said:

> Fire may be, to a great extent, prevented by the prohibition of dangerous cargo, by care in its stowing, and the exercise of judgment and discretion in its location. It may be detected by any one of the many devices that assist the senses, and it may be extinguished by the application of agencies at our command.

On behalf of the American delegation, Mr. Uhler proposed the following resolution:

> *Resolved*, That the American delegation proposes the following principle for the consideration of this subcommittee, and requests its adoption and indorsement:
>
> That the several States signatory to this conference agree to enact such legislation as will to the fullest possible extent provide for the prevention,

[8] Bureau of Equipment, U. S. Navy, Reports of the efficiency of various coals used by United States ships, 1896–1898: Jan. 27, 1898, pp. 81–85.

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detection, and extinguishing of fire on shipboard, the details of the inauguration and application of such law to be regulated and arranged by the several signatory States.

Although this was passed by the conference, apparently no concerted action along the line of the resolution has been carried out by the several countries represented.

SOURCES OF INFORMATION.

In order to obtain more information on the subject of fires in bunker or cargo coal, a questionnaire was sent out in 1922 by F. R. Wadleigh, commercial engineer, Bureau of Mines, and chief of the coal division, Department of Commerce, with the approval of the Secretary of Commerce and the director of the bureau, as follows:

DEAR SIR: The United States Bureau of Mines, in conjunction with the Department of Commerce, is engaged in making an investigation and study of coal storage and desires to include in the study the question of spontaneous combustion in coal cargoes and ships' bunkers.

It will be greatly appreciated if you will aid the investigation by furnishing any data that you may have on the subject, together with any suggestions that you may care to make as to other possible sources of information.

The data for specific cases should cover as many as possible of the following items:

Coal fires in bunkers or holds.

1. Probable cause of fire.
2. Description of coal:
   Kind.
   Size.
3. Was coal wet or dry when taken on board?
4. Part of ship at which fires occurred.
5. Length of time coal was on board or position of ship when fires were discovered.
6. How was fire handled?
7. Approximate amount of coal damaged.
8. Damage to ship, if any.
9. Did any explosions occur?

General data.

1. What measures are recommended for—
   (*a*) Prevention of fires on ships.
   (*b*) Handling of fires after they have started.
2. What effect, if any, is it considered that the condition of the coal, whether wet or dry, lumpy or small (slack), has on the starting of fires from spontaneous combustion.
3. Any other remarks, recommendations, or information bearing upon the subject.

The following preliminary presentation of the subject is based upon the replies to the above questionnaire, upon a study of available literature upon the subject, and upon interviews with a number

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of persons in Washington, Philadelphia, New York, Norfolk, Newport News, Baltimore, and many ports on the Great Lakes, engaged in various phases of coaling and the use of coal on ships. Through the courtesy of Commanders John S. Higgins and E. A. Cobey and Lieutenant Commander Woodson, of the United States Navy, data gathered by the Navy Department were also available for study.

PREVIOUS INVESTIGATIONS AND CONCLUSIONS.

The following is a brief historical résumé of a number of prior investigations of this subject in the United States and other countries.

UNITED STATES NAVY COMMISSION OF 1898—CONCLUSIONS.

In 1898, a committee of the United States Navy investigated the subject of spontaneous combustion on shipboard and in its report[9] included the following suggestions regarding fires in coal bunkers:

1. The report of the Royal Commissioners of Great Britain on fires in coal cargoes, published in 1876, and the paper of Prof. Vivian B. Lewes, of the Royal Naval College, Greenwich, published in 1891, are most important contributions to the literature of this subject.

These reports are in practical accord on the important points, and, in our opinion, as a result of careful study, give the true explanation of spontaneous ignition of coal. The paper of Professor Lewes was reprinted by the Bureau of Equipment in 1897, in the back of "Report on the Efficiency of Various Coals used by U. S. Ships, 1895–96," and a copy is to be found on all ships in commission, and at all navy yards.

2. According to Professor Abel, Doctor Percy, and Professor Lewes, the causes of spontaneous ignition of coal are:

3. First (and chiefly): The condensation and absorption of oxygen from the air by the coal, which of itself causes heating, and this promotes the chemical combination of the volatile hydrocarbons in the coal and some of the carbon itself with the condensed oxygen. This process may be described as self-stimulating, so that, with conditions favorable, sufficient heat may be generated to cause the ignition of portions of the coal.

The favorable conditions are:

(*a*) A moderately high external temperature.

(*b*) A broken condition of the coal, affording the fresh surfaces for absorbing oxygen.

(*c*) A supply of air sufficient for the purpose but not in the nature of a strong current adequate to remove the heat.

(*d*) A considerable percentage of volatile combustible matter or an extremely divided condition.

4. Second: Moisture acting upon sulphur in the form of iron pyrites.

5. The heating effect of this second cause is very small, and it acts rather by breaking the coal and presenting fresh surfaces for the absorption of oxygen.

6. While the condensation and absorption of oxygen is always going on to a limited extent, the general immunity of our bunker coal from spontaneous

[9] Bureau of Equipment, U. S. Navy, Reports of the efficiency of various coals used by United States ships, 1896–1898: Jan. 27, 1898, pp. 81–85.

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ignition shows that there must be some exciting cause, sufficient to stimulate the action to greater rapidity when fires do occur, and this we believe to be due chiefly to external heat. The analysis of the bunker fires on our own naval vessels indicate this very strongly.

7. In former days, when ships were under steam only part of the time, when steam pressures were lower, when there were no protective decks and bunkers over the boilers, and there was ample circulation of air around the boilers, cases of spontaneous ignition were almost unknown in bunkers; but modern war vessels have all these conditions changed, and for some bunkers there is sure to be, when adjacent boilers are in use, a sufficiently high external temperature to cause the spontaneous ignition of any coal at all liable to that phenomenon.

8. It should not be inferred, however, that spontaneous ignition is a frequent occurrence, even under the more favorable modern conditions. The total number of fires due to this cause, in the last three and one-half years, counting the fire in each bunker as a separate fire, is only 20 on 10 ships, and when we reflect that during that time there have been at least 40 ships in commission, averaging probably 40 bunkers each, which have probably coaled an average of 20 times, the percentage of bunker fires is seen to be very low.

9. While it is desirable, if possible, to eliminate bunker fires altogether, yet if the precautions necessary to this end require great expense or are undesirable for other good reasons, we must adopt such reasonable expedients as commend themselves to practical considerations, and to the need of each particular case.

10. In a modern war vessel, great coal-carrying capacity is one of the first considerations, and ready access to the coal from the fire rooms is almost as important. Both compel the construction of the coal bunkers in close proximity to the boilers. Moreover, the structure of such a vessel from necessity prevents any general circulation of air sufficient to prevent a considerable elevation of temperature near the bunkers. We have data of cases where such temperatures have attained 200° F. Professor Lewes recommends provision for a water wall between the bunkers and boilers or uptakes in such cases, but there are several practical objections to such a plan which we consider conclusive. A double bulkhead with air circulation involves practical objections which will be obvious on consideration, so that, in our judgment, except as stated in the next paragraph, we do not recommend any structural changes.

11. There are some bunkers in which a fire would involve great danger, namely, those adjacent to magazines, while in others the loss of the coal would be a serious matter if the ship had a small bunker capacity and was making a long passage, and in time of action such a fire, calling for extra work on the part of the engineer's forces, would be a serious matter. On the *New York* and on the *Cincinnati* there were fires in bunkers next to the magazines which caused the charring of woodwork in the latter, and if they had not, fortunately, been discovered in time, there might have been in each case a terrible disaster. For such cases, we do consider structural provision an absolute necessity, and that no magazine should ever be separated from a coal bunker by a single bulkhead only. There should always be a double bulkhead with at least 4 inches between the walls of the bunkers and magazines and with provision for a good circulation of air to carry off any heat that may come from the bunker. In order to avail ourselves of expert opinion on the structural question, we requested the views of the Chief Constructor of the Navy, and find from his reply that he had anticipated this important point, and provision is made in the new battleships on practically the plan which we recommend, while the

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Board on Construction had recommended the fitting of an additional bulkhead in the bunkers of the *New York* and adjacent to the magazines, with provision for air circulation. The precautions considered necessary to prevent fires and to discover and extinguish them in bunkers not adjacent to the magazines are presented further on.

With regard to fires in bunkers, we submit the following recommendations:

1. No magazine should be separated from a coal bunker by a single bulkhead only, but in all cases there should be a double bulkhead with efficient air circulation, artificial if necessary.

2. The temperature of spaces near bunkers, where it is likely to be high, should be observed, and where it will be sufficiently great to be likely to cause spontaneous ignition, there bunkers should be kept normally empty if the total coal capacity is sufficiently great. If they must be kept filled a coal should be chosen which is least likely to give trouble.

On our eastern coast, anthracite coal fulfills this condition completely, as diligent inquiry has not developed a single instance of spontaneous ignition of anthracite in such sizes as come on board ship. In Europe and many foreign ports this condition would be met by briquets or "patent" fuel. This is composed of bituminous slack bound together by tar, pitch, or flour paste, and from its nature and method of manufacture has not the conditions for absorbing oxygen. Where neither of these is attainable, a semibituminous coal with a low percentage of volatile combustible matter should be chosen and stowed in large lumps only.

With respect to the temperature likely to cause ignition, Professor Lewes states:

> If the bunker coal next the bulkhead be kept at 120° F., any coal with a tendency to absorb oxygen will run a great chance of igniting within a few days.

He assumes this as a probable temperature if that outside the bulkhead is 200° F. This is a point that can only be settled by experience, as the data available to us do not warrant a definite limit being assigned. Where bunkers are exposed to such great heat they should be examined, if practicable, at regular intervals, to ascertain if the temperature rises or if vapor or smoke is emitted.

3. There should be as much space as practicable between the bunkers and boilers or uptakes. This is a question of design and no hard and fast rule can be laid down. We would recommend, however, a minimum space of 10 inches from the shells of cylindrical boilers, and at least 18 inches from uptakes and the casings of water-tube boilers where the latter really serve as uptakes; and, if practicable, there should be air circulation.

4. Lump coal of large size and as free from small coal and slack as possible is to be preferred. In the ordinary purchase of coal, some slack is inevitable, but where there is room for choice, other things being equal, large lumps should be chosen. If practicable to get it, coal that was screened before shipment should be preferred.

5. Coal with a very high percentage of combustible volatile matter should be avoided when possible. Tables of analyses of various kinds of coal are usually readily obtainable, so that the percentage referred to can be found. When a coal is offered of which there is no record in accessible tables, the percentage composition can probably be obtained from reputable coal dealers, and, we may add, in our opinion, contracts should be placed only with such dealers.

6. The coal should not contain a large amount of pyrites.

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7. In choosing coals, the "Coal Efficiency Reports" will indicate the relative values of those that have been used at home and abroad, and the Admiralty list will also aid in the selection of foreign stations. In any case, coals of established reputation should be chosen, even at a higher price. This is authorized by law, and the practice is strongly urged. A standard coal is apt to be freer from slack and pyrites than coal of poor quality, and not only less liable to spontaneous ignition but also cheaper in the end. The reports show that the *Philadelphia* can steam 7,170.6 knots, using Albion Cardiff coal, at a total cost of $7,282.8, and that it would cost $7,433.7 using Comox coal, although the former costs $7.14 a ton and Comox $5.65 a ton.

8. With respect to moisture, we consider it preferable on every ground to take the coal on board dry; but, when necessary to take it on board wet, such coal should be used first, if practicable, and the bunkers in which it is put examined at regular intervals.

9. In general, recently mined coal should not be taken. The authorities already cited explain this fully. The fresh coal is more greedy of oxygen than after the absorbing process has proceeded for some time. Ordinarily our ships on foreign stations can not get freshly mined coal, so that they avoid this risk. The coal should be at least a month from the mine.

10. Precautions should be taken to prevent waste or oil from getting into the bunkers, and old coal should be used before that recently received.

11. With respect to the extinguishing of fires in bunkers, the means now provided appear the best practicable. The Bureau of Steam Engineering provides a steam pipe to each bunker in order that, in case of fire, an atmosphere of steam which will not support combustion may drive out the air. The reports show that these have been employed effectively; but it has been suggested that, if the pipes for admitting the steam were placed on the bottom of the bunker instead of the top, the system would prove more efficient. Otherwise the steam escapes through the bunker exhaust pipes. The bunkers can always be flooded through the coal scuttles if that can be found necessary. As a rule, the coal should be removed from the bunker after it has once fired. The facility of removal depends on the location of the bunker and the total amount of coal on hand. With the extensive water-tight subdivision now carried out, and the inevitable restrictions on design in war vessels, we are not aware that any change could be made to facilitate the emptying of bunkers when a fire has occurred.

FOREIGN INVESTIGATIONS.

ROYAL COMMISSION OF NEW SOUTH WALES, 1897–1900.

One of the earliest investigations of the subject, and one frequently referred to in British literature, was that carried on by a Royal commission in New South Wales, under the presidency of Prof. Richard Threlfall.[10] During an unusually hot summer, about 1895 or 1896, a number of ships were lost by fire within a short interval; this was the incentive for the appointment of the commission, which reported first in 1897, and again in 1900, giving the result of investigations and experiments in Australia and in England between 1896 and 1900.

[10] Report of the Royal Commission of New South Wales, appointed July 8, 1896, to inquire into the cause of the dangers to which vessels carrying coal are said to be peculiarly liable, and as to the best means which can be adopted for removing or lessening the same, Sydney, N. S. W., 1900.

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A copy of this report has not been available, for consultation, but the following conclusions are taken from the testimony of Professor Threlfall before the British Royal Commission on Coal Supplies, and printed in the second report.[11] Professor Threlfall said:

I believe I have had before me the reports of every inquiry that has been held either in England or in America or in any of the English colonies on the subject of spontaneous fires at sea.

The conclusion is a very simple one: It is that the cause of heating is the gradual oxidation of the coal by air. * * * The velocity of the reaction is simply a question of temperature; and whether the coal will heat or not depends upon whether the heat that is generated can get away faster than it is formed. If it can not get away as fast as it is formed, then you have the coal heating, and the rate at which the oxygen is absorbed also is a matter which depends upon the temperature and goes on much more rapidly as the temperature rises.

The coal has to be of a certain kind of fineness; of course, if it is too fine the air does not get into it and then it does not get a chance of being absorbed; and if it is too coarse, then you do not get the necessary surface for the absorption.

In the experiments with moisture, we had two bins of coal, each of them of 245 tons, and these were built side by side under identically the same conditions, the only difference being that alternate barrows of coal were put into the two bins, and a hose was sprayed on the one while the coal was being put in; it was played in gently so as not to wash out dust. The result was that we had one bin of dry coal and another of wet coal. * * * It was Australian coal, from Newcastle. * * * The dry coal heated up in the regular way until it got to 200° C., when we stopped it—it was just on the point of firing.

* * * It was supposed to represent its condition on board ship exactly; the bins each had a roof several feet above the top of the coal. The result was that the temperature rose gradually from, I think, about 40° C., which was the temperature it started at.

* * * The coal in the wet bin started at about 30°; the effect of the wetting had been to cool it about 10°; * * * the maximum temperature never got above 47° C. or thereabouts.

In 1876 there was an English commission on the subject, and the question was put as to whether dry coal or wet coal was the more dangerous, to 27 witnesses; and those 27 witnesses all said that wet coal was the more dangerous. It turned out that of those 27 answers 26 were from hearsay only, and there was only one of the witnesses * * * who gave evidence at first hand; * * * it really broke down in cross-examination.

The result is that there is really no evidence to substantiate it, but it has been an old prejudice, which I believe has risen from the time when people thought that the heating of coal was something like the heating of hay and that it depended upon a fermenation process, but it has unfortunately gotten into the textboks, and I need hardly say that has made it almost imperishable.

Fayol, the great French authority * * * made the same experiments with small heaps of coal 30 years ago, and has come to the same conclusion.

As a result of these experiments, the British Board of Trade[12] rescinded its regulation compelling captains who had a cargo of coal

[11] Second report of the Royal Commission on Coal Supplies, London, vol. 1, 1904, pp. 227–228, par. 14085–14092, 14095, 14096, 14100.

[12] Work cited, p. 228, par. 14105.

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which was found to be wet to discharge such cargo, and they can no longer compel the cargo to be discharged; but they have not gone so far as to specify that the coal shall be wet when loaded.

MILTON REPORT TO LLOYD'S REGISTER, 1912.

In 1912, the chief engineer surveyor of Lloyd's Register of Shippings,[13] reported that very varied opinions have been held at different times as to the causes of spontaneous combustion, and the best means to prevent its occurrence. He gave the following conclusions:

Concerning bunkers, the conditions regarding which are so different from those applying to holds, and in which, while they are being worked, it is necessary to have an ample ventilation throughout, it is desirable that the engineers of the vessels should realize the conditions tending to overheating and combustion, so that in each particular case they may take such precautions as may be possible. Amongst other points they should understand:

1. That all coal gives off some inflammable gas when freshly worked, and also when freshly broken, and that this gas becomes explosive when mixed with certain proportions of air. It is the evolution of this gas which requires the ventilation of the bunkers before entering them with naked lights.

2. That heating of coal, and the consequent risk of spontaneous combustion, does not proceed from the presence of gas, but is caused by the absorption of oxygen from the air.

3. That this absorption, and the accompanying development of heat, is greater at high than at low temperatures, so that, when once commenced, it proceeds at an increasing rate if the supply of air is maintained.

4. That where heat is being generated by the absorption of oxygen it is probable that more gas will be evolved. The evolution of the gas, however, does not cause the generation of heat. Where such gas is being evolved, if sufficient supply of air is maintained to provide more oxygen than is being absorbed, an explosive mixture is formed amongst the coal.

5. To minimize the absorption of oxygen by the coal in reserve bunkers, or in any bunker in which men are not actually working, the lower doors should be kept absolutely closed, so as to prevent any current of air whatever passing through the bunker and into the mass of coals.

6. If there are any parts of bunkers in which, owing to the proximity of boilers, uptakes, or recesses through which steam pipes, etc., are carried, there is likely to be a higher than normal temperature, these parts should, if possible, be stowed with large coal, and should be worked out as soon as possible. The chutes should be arranged not to deliver small coal into these places.

7. Small coal which accumulates under chutes, etc., should be worked out as soon as possible, and not left till the last.

8. If any coal is left in a bunker when a fresh charge has to be taken in, it should be trimmed into a position to insure its being used on the next voyage. It can not be too strongly impressed upon those responsible that danger of overheating and spontaneous combustion increases with the length of time the coal remains in the ship.

9. Where bunkers are over gutterways, etc., special care should be taken that the limbers are tight. Several fires have originated in bunkers just over

[13] Report of the chief engineer surveyor on fires on board ship, Lloyd's Register of Shipping, London, 1921, pp. 4–7.

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the limbers, and there is reason to suppose that they have been caused by air circulating through the coal and coming from the limbers.

10. There is no risk entailed by the coal being wet when put on board. In fact, in cases where coal is known to be of a firey nature, it would be of an advantage for the small coal to be damped when charging the bunkers.

11. If heating of any part should occur where there is no traceable external source of heat to account for it, the heating will probably be local only in a part where the coal is small, and the surrounding portions may not be overheated. In attempting to obtain access to the heated parts for the purpose of applying water, special care is requisite to prevent an inrush of air such as might convert a heated zone into an actual fire.

12. Although some kinds of coal have proved to be more liable to spontaneous heating and combustion than others, it should be realized that all coal, even anthracite,[14] is liable to these occurrences.

OTHER REPORTS.

S. D. McComb has written a valuable article on "Some suggestions for reducing the loss by fire on vessels."[15]

In the Journal of the Royal Society of Arts, June 20, 1916, in an article on spontaneous combustion in ships' cargoes,[16] the following points were brought out:

Spontaneous combustion is due to chemical and physical changes in bodies partly or mainly carbonaceous under the influence of atmospheric oxygen, and sufficient heat is thus generated to give rise ultimately to combustion.

Lump coal is less liable to spontaneous combustion than small.

Sprinkle or spray with water or coal tar to exclude moisture.

Avoid breakage.

Most trouble is directly under hatchways where coal dust collects.

Observe the temperature at regular intervals, and put the results in the log of the ship.

Select the coal shown to be least liable to spontaneous combustion.

Inspect the ship with a safety lamp.

Do not ventilate the coal by air shafts, for three ships having coal ventilated were lost between England and India, while one not ventilated but loaded like the others, went through safely.

Provide means for escape from the hold of any waste gas given off by coal.

Deaden fire by the use of carbonic acid gas.

Urge that information on the subject be given in navigation schools and nautical examinations.

REPORT OF BRITISH COMMITTEE ON SPONTANEOUS COMBUSTION IN COAL MINES, 1921.

In 1921, the final report of the British Departmental Committee on Spontaneous Combustion in Coal Mines was made.[17] This report

[14] This does not refer to Pennsylvania anthracite, which does not fire spontaneously.—H. H. S.

[15] McComb, S. D., Some suggestions for reducing the loss by fire on vessels: Trans. Soc. Naval Arch. and Marine Eng., vol. 18, 1910, p. 191.

[16] Jour. Royal Soc. Arts, June 20, 1916.

[17] Final report of the Departmental Committee on Spontaneous Combustion of Coal in Mines: London, 1921, p. 107.

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contains much material upon the spontaneous combustion of coal in mines, but the only conclusion pertinent to spontaneous combustion of coal on ships is the general statement:

> Probably all bituminous coal is liable to spontaneous combustion in some degree; but the fact that there is greater liability to self-heating of the coal in the seams of some coal fields of the United Kingdom than in others is due to several causes other than the chemical composition of the coal.

REPORT OF FIRES ON BRITISH SHIPS AUGUST 1, 1919, TO JULY 31, 1920.

In 1921, there appeared the latest available report on fires that occurred on British ships between August 1, 1919, and July 31, 1920.[18]

This report was brought about by attention being drawn to the subject of the numbers of fires in bunkers and cargoes of coal on British ships by the Liverpool Board of Trade, the Underwriters Association, and Lloyd's. An investigation was made by the board of trade surveyors, wherever practicable, of all ship fires reported, 114 in number. A summary giving many of the salient points of this report has been published and distributed by Lloyd's Register of Shipping.

In this report, 242 fires are recorded under the following heads:

1. Name of vessel; port of entry; official number.
2. Voyage of cargo.
3. Nature of coal in bunker; where shipped; ventilation.
4. Particulars of casualty.

A summary of the report shows that 38 cargo fires were attributed to other causes than coal. Forty-two fires were attributed to supposed carelessness, such as smoking, and four were attributed to incendiaries, although there was no definite evidence of incendiarism. Other causes of fire were: Short circuit of electric wire, 6; oil and paraffin from lamp, 29.

Seventy-four bunker fires were reported, in most of which the damage to the vessel was not serious, but three vessels were lost. In four ships where fires occurred, coal was being carried as cargo. One fire was due to an explosion of coal gas from lack of surface ventilation. Spontaneous combustion was the attributed cause of two other fires, and the remaining fire was said to have been caused by drunken trimmers leaving lighted candles in the hold, thus firing the coal.

For about half the bunker fires, the cause given was spontaneous combustion, or supposed spontaneous combustion. Other causes were "hot ashes," "heat from funnel gases," and "supposed in-

[18] Great Britain Board of Trade, Report on fires which occurred or were reported on British ships during the period 1st August, 1919, and 31st July, 1920: London, 1921.

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cendiarism." Such indefinite statements as "smoke was seen," "fire was reported," "coal heating," and "coal overheated" were given, but it is probable that spontaneous combustion was the real cause.

Coal in which fires occurred was mined in the following countries:

United States	22	Australia	4
South Africa	8	Scotland	2
England	21	Asia	7
Canada	2	Germany	1
Wales	5		

A few quotations from the causes given in the detailed descriptions of the fires are of interest:

There are several collieries in Yorkshire, and no doubt in other places, where the dirt,[19] which is of the same appearance as the coal, without the bright luster, is very liable to spontaneous combustion. This dirt lies between the true seams of coal and the roof and the bottom of the seam as worked. It is usually cleaned out of the coal. It is the cause of gob fires in the pits. * * *

It seems probable that rain or sea water entered through a hatch and generated heat in the Yorkshire coal, which possibly was accentuated by the mixture of American coal, and also by the heat of the adjacent boiler. * * *

The bunkers had been previously practically empty. The vessel had emergency smoke ducts, which passed from the base of the funnel through the bridge space at the ship's sides. When the war ended these were no longer required, so the portions between the funnel casing and the ship's side were removed and plates fitted to blank the holes that remained. The funnel gases were therefore on one side of the plate and the coal on the other, so that the coal ignited owing to the heat. The second fire was probably caused by the coal still being hot when it was put back into the bunkers. That which was in the vertical pocket would have a constant current of air passing through it, thus fanning it into a red heat. * * *

It was caused by spontaneous combustion, due to the bunkers not having been thoroughly cleared of coal for a long time. * * *

The captain was quite sure that the fire originated in coal between two large ventilators, and it is possible that the fire originated here, owing to a match thrown down when loading. * * *

Small bituminous coal was kept for some three months at the bottom of a partially empty cross bunker which adjoined the stoke hold. Continuous air currents would permit the oxidation of the coal. Through the spaces between the boards forming the bunker wall a small amount of air circulated, sufficient to maintain combustion, but not of sufficient quantity to have any effect in cooling the coal. * * *

Fire was caused by spontaneous combustion, and the outbreak occurred at the wood bulkhead, the leakage of air through the plank seams promoting combustion where small pockets of gas formed.

Fire appears to have started about the junction of the Yorkshire and the Welsh coal, and for two days before the outbreak a strong smell of petrol was detected coming from the bunker. * * *

[19] It would be interesting to know if "dirt" as here used does not include fine coal or possibly mother coal.—H. H. S.

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The fire appears to have occurred in the Yorkshire coal, which was "large and small" in equal quantities, and had been in the ship for some time exposed to air under circumstances favorable to becoming dry and for absorption of air. These circumstances might be considered favorable to produce spontaneous combustion in the Yorkshire coal after it had been covered with the coal taken on at Avonmouth. * * *

It appears that the port side of the ship on which the fire occurred was away from the quay and exposed to the tropical sun most of the time at the numerous ports of call, and this heat favored spontaneous combustion. The space was well ventilated and the hatchways kept open. * * *

This fire, from the information received, appears to have been entirely due to the nature of the coal. The origin of the coal is not known, but it is assumed to be Australian and Javanese. * * *

The rise of temperature was not caused by any inadequate ventilation of the bunker, as during part of the time the temperature on deck was higher than in the bunker. Also, there was usually a draft from the bunker to the stokehold. Neither had the temperature of the stokehold any bearing on the cause; but the rise of temperature in the coal was due to natural causes inherent in the coal itself, its condition when put on board and the time (over two and a half months) during which it had been lying under conditions suitable to the generation of heat. * * *

American coal has been found to be liable to spontaneous combustion if allowed to remain in one position for a considerable period, especially if under pressure. * * *

Ship's officers stated that they had experienced fires with Australian coal on several occasions and expressed opinion that the fire was not an extraordinary occurrence. In his opinion the fire was not caused by heat from the boiler room, as the seat of the fire was some 24 feet from the stokehold bulkhead. It should be set down to spontaneous combustion. The fire took place in the lower cross bunker. It was nearly full of coal, but was not well trimmed, and contained about 655 tons.

RECOMMENDATIONS OF BRITISH BOARD OF TRADE.

The engineer-in-chief of the Board of Trade in the appendix to the English report made the following comments and recommendations.[20]

There appears to be evidence that, where partly empty bunkers are filled with coal, the coal which has been left in the bunker is liable to become overheated and to fire.

Nearly all the fires occurred in the bunkers. These are situated near the stokeholds and are exposed to the heat of the stokehold, which would naturally hasten the process of spontaneous combustion. * * *

Some coal appears especially liable to spontaneous combustion, as exemplified by fires on a number of ships, coal in which came from the same source. * * *

In one case where steam was used to extinguish the fire a succession of explosions occurred, but explosions have also occurred in cases where there is no mention of steam having been used for extinguishing purposes. These have been due to the distillation of coal gas by heat which, mixing with the proper proportion of air, has exploded on contact with fire. * * *

In two of the vessels in which fires occurred, which were both originally German steamers, the coal had been in the bunker some years. The next

[20] Great Britain Board of Trade, Report on fires which occurred or were reported on British ships during the period 1st August, 1919, and 31st July, 1920. London, 1921.

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longest period was six months. The period of heating until fire actually occurred appears to have been between three weeks and three and one-half months. Exceptional cases occur in which the bunkers were coaled after having been swept out and fire broke out in one bunker within four days, and in another within a few days, while the vessel was still in port. * * *

Bunkers should be tight, to prevent air from passing through the coal, and thus providing oxygen, the absorption of which is attended with overheating. Unless the heat of absorption can be carried off as quickly as it is generated, overheating will occur. Coal remaining in bunkers should be moved to where it can be used first. Small coal is more liable to spontaneous combustion than large coal. Water is the best medium for extinguishing coal fires.

It might be added that all coal is apparently liable to spontaneous combustion. When it does occur on board ship it is due probably to fortuitous conditions in regard to the rate and supply of air (oxygen) and the rate of escape of the heat generated. A slight change of the conditions either way may mean the difference between overheating and the absence of it. Hence a ship may carry coal in the bunkers without fires occurring over a long period of years. * * *

SPONTANEOUS COMBUSTION.

Although many of the principles underlying the spontaneous combustion of coal are shown by the preceding reports to have been formulated at various times during the past 30 years and by a number of different boards and committees, it is quite evident that comparatively few of these connected with the shipping industry have become conversant with them. An effort will therefore be made to restate the general principles which have been already given and have been verified by later researches, and to supplement them by a summary of what seems to be the best practice at present in regard to placing coal in bunkers and cargoes.

A complete discussion of the causes of the spontaneous combustion of coal will be found in bulletins and technical papers of the Bureau of Mines, the Engineering Experiment Station of the University of Illinois, the Canadian Department of Mines, various departments of the British Government, and technical and trade publications, but the following discussion gives the essential factors.

KIND OF COAL.

All kinds of bituminous coal are included in the statements of this section, for while some are more liable to spontaneous combustion than others, it is not possible to say that any given kind will or will not ignite spontaneously if conditions for spontaneous combustion are favorable.

The evidence shows conclusively that all bituminous coals have kept without firing, and it is equally true that all varieties have fired under certain conditions. This does not mean that all coals are equally free from spontaneous combustion, as the storage qualities of

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coals from different districts undoubtedly differ. The evidence also shows conclusively that it is not so much the kind of coal or the district it comes from as it is the size of the coal and the way in which it is handled that influence firing. If investigation shows that coal from a certain district, or even from a given mine, has fired frequently, common sense suggests not buying such coal for shipment if it can be avoided. This has been recognized by the United States Navy, which has a list of accepted mines from which coal may be purchased. Clean, screened coal, with as small an amount as possible below one-half inch in size, is least liable to spontaneous combustion, from whatever district it may come. W. S. Gould says that "crop coal" will heat more readily than coal from under deep cover and that coal once heated but later cooled will heat more readily than coal that has not once heated. This latter opinion has been contested.

Many believe that certain coals have inherent qualities that render them particularly liable to spontaneous combustion, but at this time coals for storage purposes are not chosen by composition alone. Extended research, which may have a bearing upon this subject, is in progress in the United States and in England as to the exact chemical composition of coal; but as yet nothing has been published that is of assistance in differentiating coals as to their liability to spontaneous combustion.

As far as is known, neither American nor Welsh anthracite is subject to spontaneous combustion.

The British report on spontaneous combustion in mines for 1921 [21] says that some coal fields are practically free from the danger of spontaneous combustion, which is most frequent in North and South Staffordshire, Warwickshire, Yorkshire, Lancashire, Forest of Dean, and Fifeshire.

A number of ship captains stated to the writer that Welsh coal is more liable to spontaneous combustion than coal from the north and east of England and from Scotland; a number of others held just the reverse opinion. Many claim that German coals are more liable to spontaneous combustion than those from England and Scotland, but there are no statistics to support this contention.

The theory that low-volatile coal is less liable to spontaneous combustion than high-volatile does not seem to be borne out by the statistics available and particularly by the results obtained in storing coal on land. The opinion seems based more on prejudice than on fact. American high-volatile coals are usually harder than low-volatile and under the same handling give less fine coal than low-volatile.

[21] Final Report of the Departmental Committee on Spontaneous Combustion of Coal in Mines: London, 1921, p. 31.

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CAUSE.

Spontaneous combustion is due to chemical and physical changes, under the influence of atmospheric oxygen, in bodies that are partly or mainly carbonaceous. This carbonaceous material and the iron pyrites in the coal generate heat when oxidized. Unless this heat is carried off by an adequate air supply passing over the substances that are undergoing oxidation, the temperature will rise to the point of ignition of the coal and spontaneous combustion will take place. Even though ignition may not result, the temperature of the coal may rise to such an extent that valuable volatile products are given off and the heating value of the coal, its gas-making properties, or its value for making coke may depreciate somewhat.

If air could be totally excluded, there would be no self-heating and no combustion. A certain amount of air circulation through the mass of coal will permit its oxidation and lead to combustion. Free circulation may carry off the heat produced, and so keep the temperature below the danger point. The commencement of heating is often indicated by a distinctive odor given off by the coal. In some bunker fires reported, the statements are made that "A smell of naphtha was noticed coming from the coal," "a strong smell of petrol was detected coming from the bunker," or "fumes were noticed coming from the coal."

As the principal factor in spontaneous combustion is the heat due to the oxidation of the carbon in the coal, the greater the surface exposed to the air—that is, the finer the coal—the greater is its liability to spontaneous combustion. Therefore, as far as possible, fine coal, particularly coal dust, should be kept out of coal that is to be stored for any length of time. Coal should therefore be screened, if possible, to remove the small coal and dust, but this may be impracticable, as most American coals are loaded on ships as run-of-mine. If it is necessary to ship, as cargo or in bunkers, large quantities of unscreened coal, run-of-mine, or screenings, the coal must be watched more carefully than screened coal.

SULPHUR IN COAL.

Sulphur occurs in practically all coal, though in widely differing amounts. It may occur combined with iron, in what is known as pyritic sulphur, or in some organic form. As far as is known, only pyritic sulphur affects spontaneous combustion. This should be kept in mind, for the proportion of total sulphur in many coals that is organic is not generally appreciated. The oxidation of pyritic sulphur produces heat and assists in breaking up the lumps of coal, and thus not only helps to increase the temperature but adds to the amount of fine coal in the pile. A rise in temperature,

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from either external or internal causes, promotes the oxidation of pyrite (as does probably the presence of moisture), and thus increases the liability of the coal to spontaneous combustion. It is wise to select low-sulphur coal if procurable, but a low-sulphur coal is not necessarily free from the danger of spontaneous combustion, and high-sulphur coals are not necessarily dangerous.

The idea that was formerly generally held that sulphur is the determining element in the spontaneous combustion of coal still prevails widely among marine users of coal, although the American and English reports quoted earlier in this paper indicate that the oxidation of carbon was long ago recognized as the chief agent in spontaneous combustion and the sulphur merely an assistant.

AMOUNT OF AIR REQUIRED FOR SPONTANEOUS COMBUSTION.

As oxygen is required for spontaneous combustion, if the air supply can be cut off by immersing coal under water or in an inert gas like CO_2, packing the coal in the pile, or confining it in an air-tight space, oxygen in the air near the coal will soon be exhausted and spontaneous combustion will not result. Underwater storage is expensive and impracticable on shipboard, as is also packing the coal to exclude oxygen from the interior of the pile.

As the oxidation of the carbon in the coal is inevitable, if oxygen can come in contact with it, sufficient air is necessary to pass through the coal pile and carry off the heat generated, thus keeping the temperature of the pile below the ignition point of the coal. If the supply of air is inadequate, the temperature will gradually rise and spontaneous combustion ensue.

VENTILATION OF COAL.

Wide divergence of opinion exists in regard to the ventilation of bunker and cargo coal. Many marine men claim that hatches should be battened tightly as soon as possible after the coal is placed in them. Others are equally insistent that the hatches should be opened whenever the weather is clear, so that the air may pass over the surface of the coal, but if heating begins the hatches should be put on and air excluded as much as possible. Many claim that adequate ventilation is furnished by the usual ship ventilators leading from the holds. One ship captain claims to have had best results by so trimming the coal as to leave open spaces in the corners of the bunkers for circulation of air. Some have attempted so to pile the lump as to form chimneys throughout the pile, although the consensus of opinion is against such practices, and with modern methods of loading vessels they are impracticable.

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The regulating of the ventilation for coal on shipboard is important. On the one hand, if air can not penetrate with sufficient rapidity the oxygen gets slowly used up and the coal may heat a little, but will cool off slowly by conduction. On the other extreme, if the air supply could be sufficiently great, the good air current would carry off the heat and again cool the mass, even though oxidation would occur to the maximum extent possible for the temperature attained. The whole difficulty is to provide this large excess of air, for if insufficient for any reason it will evidently promote ignition by freely supplying the necessary oxygen. It is emphasized in the report of the Royal Commission on the Spontaneous Combustion of Coal in Ships, 1876, that of four vessels laden with between 1,500 and 2,000 tons of the same coals shipped at the same time at Newcastle for Bombay, only one arrived safely, and that the one in which no attempt at ventilation was made.

After a careful consideration of the conclusions arrived at by the Royal commissioners of 1875 and by Professor Threlfall and of the experiments conducted by M. Fayol, it is definitely established that coal cargoes should not have any through ventilation. The very thorough ventilation by dividing the cargo up into numerous separated layers, suggested by M. Fayol, is quite impracticable. Even if the division could be carried out, there would be great difficulty in arranging such through currents of air as to insure sufficient circulation in every place where there was an accumulation of small coal and dust, to carry away the heat generated by the oxidation caused by the limited air supply.

The surface ventilation now always provided, if the coal is properly stacked, safeguards against the accumulation above the coal of marsh gas or other inflammable gases evolved from the coal, and the consequent risk of explosion; but it is a question whether this ventilation, supplemented as it frequently is by the opening of the hatches in fine weather, does not aid in producing heating of the coal and the risk of spontaneous combustion by supplying to the body of the coal the limited quantity of air necessary to permit of the slow absorption of oxygen, which is the cause of the heating of the coal. It would be safer as regards heating if M. Fayol's suggestion of hermetically sealing the holds could be carried out, arranging, however, provision for the escape of the marsh gas evolved during the voyage. If this method could be adopted, care would have to be taken to ventilate thoroughly the surface and the vacant spaces in the holds before discharging the cargo. Moreover, as the holds would soon become full of gas in all the interstitial spaces between the pieces of coal, special attention would have to be given to prevent leakage of dangerous gas through sounding pipes, bilges, and deck pump suction pipes. Such care would not be greater than that

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habitually given to such matters in vessels carrying petroleum in bulk.

In his book, "Stowage and Dangerous Cargo," H. K. Barr says:[22]

> The important question of ventilating coal cargoes has given rise at different times to much anxious inquiry. A step in the right direction was taken when the coal commission in New York stopped the through ventilating system and instructed ship masters to continue surface ventilating only. It was pointed out that air, to do any good, would have to sweep continuously and freely through every part of the cargo, a condition not obtainable on a ship. The admission of small quantities of air through shafts has been found sufficient to aid spontaneous ignition but not to ventilate the cargo. The commission recommended that the temperature in different parts of the hold be taken daily and noted in the ship's book. A system of surface ventilation should be carried out, which will be effective in all weather and afford continuous escape to the open air (independent of the hatchways) of gas, which is especially dangerous during the first part of a voyage.

The distinction between "through ventilation"—that is, currents of air throughout the coal from bottom to top, and surface ventilation, or allowing air to reach only the top surface of the pile, should be kept in mind. Instead of recording temperatures in the ship's book where they may be overlooked, it would seem better to use a separate sheet, so that the temperature readings would be brought prominently to the attention of those who should know them.

The necessity of providing adequately for the escape of the gases given off by the coal is conclusively shown by the explosion on the steamship *Adriatic*, described on pages 6 to 13.

EFFECT OF MOISTURE.

Opinions differ widely as to the effect of moisture upon spontaneous combustion, and the idea formerly almost universally held that moisture assists spontaneous combustion is still popular though the evidence seems to be against the idea. Many hold that it is advisable to wet down coal when it is placed in the bunkers, but this opinion too often is biased, due to the great disadvantage of working in dry coal in a confined space. The opinions given in response to the questionnaire are very inconclusive, although in most of the fires noted the coal was said to be damp or wet. The diverse opinions in regard to the effects of moisture are in some cases, at least, due to the failure to distinguish between moist coal and coal that has been wet down and therefore holds a large amount of moisture.

Prof. Threlfall's testimony regarding[23] the tests by the New South Wales commission includes an account of experiments with two bins 21 feet square loaded with the same coal, one kept dry and the other saturated from a hose until water ran off in a small stream. The

[22] Barr, H. K., Stowage and dangerous cargo, 1918, p. 21.

[23] Second report of the Royal Commission on Coal Supplies, London, vol. 1, 1904, pp. 227–228, par. 14089–14092, 14095, 14096.

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dry coal heated, but the wet did not. The result was said to prove conclusively that dry coal was more dangerous, and that the view of the British Royal Commission on the spontaneous combustion of coal on ships (1876), supported generally by evidence before other commissions, that wet coal was most dangerous, should be abandoned. The experiment really proved only that when sufficient water was present to prevent appreciable access of oxygen to the coal surface, it would not heat. If the moisture present is not sufficient to exclude oxygen from the surface, there is every reason for still believing that it will materially assist chemical action.

Doane [24] states that the amount of moisture in an air-dried bituminous fuel is a measure of the risk from spontaneous ignition, and that bituminous coal with over 4.75 per cent is most dangerous. There is little reason, however, for believing that moisture can be such an important factor of itself. In the oxidation of pyrites it plays an important part.

In view of the New South Wales results referred to above, it has been suggested that water should be played from a hose upon the coal accumulated beneath the hatchways when loading. It is estimated that 10 per cent of water prevents heating, and assuming that coal as shipped contains from 2 to 3 per cent of water, the additional water demanded would be 8 per cent on approximately one-fifteenth of the whole cargo, equal to only a half per cent on the total cargo.[25] If the quantity of water could be maintained in the crushed coal, it would, no doubt, be effective, but under the conditions existing in the hold it would almost certainly become more evenly distributed throughout the rest of the coal, when the net result would be the absence of a wet, safe, and limited mass of coal, and the presence of a moist, finely divided mass in a condition peculiarly liable to oxidation.

A distinction should be made between wet or saturated coal such as was used in the New South Wales experiment and coal that is simply wet or damp from atmospheric moisture, rain, or snow. If coal could be kept so thoroughly wet that the dust would be pasty a condition approaching underwater storage would prevail, but this would add considerable weight to the load of the ship. A ship must take on coal irrespective of the weather, and the opinions of those superintending the loading of coal are that it makes little difference whether it is loaded wet or dry. As previously noted, the British regulations were changed after the Australian investigations, so that the placing of wet coal on shipboard was not pro-

[24] Doane, Alfred O., The spontaneous ignition of coal: Eng. News, vol. 52, Aug. 18, 1904, p. 141.

[25] Threlfall, Richard, The spontaneous heating of coal, particularly during shipment: Jour. Soc. Chem. Ind., vol. 28, July 31, 1909, pp. 759–773.

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hibited. Professor Threlfall urged strongly that coal be wetted down, but there is no record that this has been made a regulation in England, even though the prohibition against wet coal was removed.

PLACING COAL ON SHIPBOARD.

Coal, if dumped upon a conical pile, will segregate into sizes, as shown in Figure 4, thus setting up a condition that is particularly conducive to spontaneous combustion, as it permits a free circulation of air through the base of the pile, but provides a seal of fine coal toward the top which prevents the heated gases from escaping and thus causes a rise of temperature sufficient to produce spontaneous combustion. To avoid this condition the coal should be trimmed in horizontal layers, so that the cargo may be as nearly uniform as possible throughout and the segregation of different sizes prevented. This method of piling was insisted upon by the Railway Fuel Administration during the war period for railroad storage of

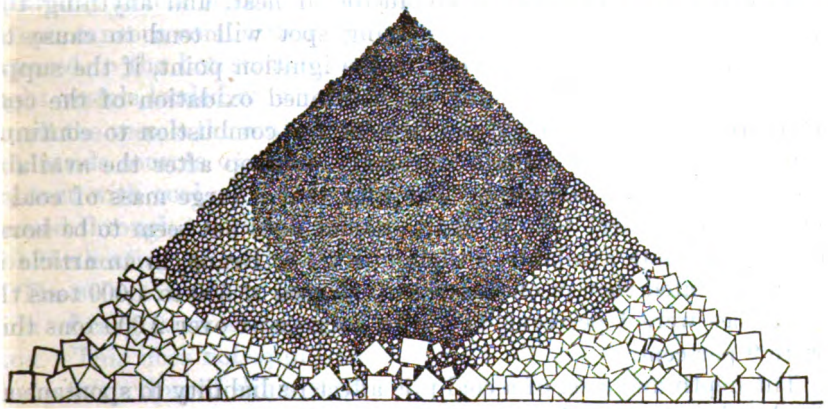

FIG. 4.—Segregation of different sizes of coal in a conical pile.

coal, and results indicated that when coal had been thus piled there was a minimum of difficulty from spontaneous combustion. The thinner the layers and the longer the time between laying down successive layers, the better; but of course on shipboard there is no time for the seasoning of successive layers, as is true in land storage. Particular attention should therefore be given to trimming in horizontal layers rather than in conical piles.

Mechanical trimmers give a more uniform distribution of coal in horizontal layers and should prevent the segregation of sizes better than hand trimming, as it is difficult to get men to trim by hand carefully, owing to the dust and the unfavorable working conditions in a bunker or hold.

A number of writers and the report of the New South Wales commission have stated that fires in coal cargoes start directly under-

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neath the hatchways, but others assert with equal positiveness that fire starts low down in the cargo. Evidence is, therefore, conflicting as to where firing may be expected to start in a bunker or hold. In the absence of statistical data on this point, it is probable that, although the point of initial heating may be anywhere within a coal pile, if coal is discharged into a hold or bunker by always dumping it at the same point on top of a cone so that the sizes will segregate, the coarse lumps rolling to the bottom and the fine staying on top, the point of initial heating may be expected to be not far from the top, at the point where the fine coal acts as a seal to impede the upward trend of air through the pile. W. S. Gould, a New York fuel engineer, says:

> In my experience fires or high temperatures have always occurred directly under the hatchways, 5 to 8 feet from the top of the pile, or from the cone under the hatchways. Fire will often creep considerable distances through a mass of coal, following the air, and break out far from the initial point.

A mass of coal is a poor conductor of heat, and anything that prevents the cooling off of a heating spot will tend to cause the temperature at that spot to rise to the ignition point, if the supply of oxygen present suffices for the continued oxidation of the coal. If there is not enough oxygen present for combustion to continue, the temperature will remain stationary or drop after the available oxygen has been exhausted. The idea that a large mass of coal is more likely to heat than a small amount does not seem to be borne out by any data available, although J. S. S. Brane, in an article in "Fuel," stated that in one record of cargoes of 500 to 1,000 tons the casualties were 1 per cent, and with cargoes of over 2,000 tons they were 9 per cent.

The depth and area of a coal pile affect its liability to spontaneous combustion, mainly through the greater difficulty of testing the pile for heating and the longer time necessary to get at a hot spot in a large pile than in a small one; also, with a deep pile there is usually more breakage in handling. On this point the report of the chief engineer surveyor of Lloyds' Register of Shipping, previously quoted, says:[26]

> In loading cargoes with the usual tips accumulation under hatchways is unavoidable; the distribution of such crushed material has been suggested, but obviously this would be a matter of difficulty in the hold of a ship, and the adoption of more modern methods which lessen the crushing is the correct solution of the problem. In stacking coal this distribution can be conveniently arranged, and small coal amongst larger sizes checks to a great degree the access of air to the mass; further, by building up in sections, or simultaneously, in more than one stack, a period may be allowed to elapse before successive

[26] Report by the chief engineer surveyor on fires on board ship, Lloyds' Register of Shipping, London, 1912.

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layers are added, so that the initial oxidation may have made considerable progress in the top layer before another is added.

EFFECT OF TEMPERATURE.

The liability of coal to spontaneous combustion increases with temperature; that is, coal put in storage at 80° F. will oxidize and thus produce heat more readily than the same coal put in storage at a temperature of 60° F. Just how much the liability increases with temperature can not be stated, but it is known definitely that coal put in bunkers or cargoes during the hot months of summer is more liable to spontaneous combustion than if similarly placed in a cooler climate or a cooler season of the year, and that as vessels pass through tropical regions greater care must be taken in observing the temperature of the coal. It was noted that when one vessel tied up at the dock, the same side was always facing in the same direction—toward the south—and that bunker heating always took place on that side. Similarly it has been noted in land storage piles that the liability to spontaneous combustion was greater on the side of the pile most exposed to the hot summer sun. W. S. Gould cites an instance of eight vessels loaded on a very hot day when the humidity was high. In all the vessels the coal heated within seven days.

Outside sources of heat, such as steam pipes, should not come in contact with coal. In spite of this, steam pipes in some ships are passed through the coal spaces and afford an excellent initial point for the heating of the coal.

The evidence of the questionnaires does not point to any one portion of cargo coal as being especially liable to spontaneous combustion. This does not apply, of course, to bunker coal, for, owing to the construction of ships, some of the bunkers are necessarily placed most disadvantageously above and around the boiler room, and the heating of such bunker coal may be expected, as in certain modern power plants on land, where the heating of the coal in the overhead bunkers nearest the boilers is common. It is recognized that the most dangerous place for an inflammable cargo is near the bunkers, as the partitions may burn through, due to the heating of the coal. The separation of bunkers from cargo spaces by double walls and ventilated spaces has been recommended, but it is seldom done, owing to the necessity for economizing space, except where unusual precautions must be taken, as when explosives or unusually combustible materials constitute the cargo. Coal placed on an open deck above the boiler room has fired in a voyage from the West Indies to New York.

TIME NECESSARY FOR SPONTANEOUS COMBUSTION TO DEVELOP.

The answers to the questionnaires showed spontaneous combustion to have developed in periods varying from 5 to 177 days; and the

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time element seems to depend very largely upon the climate and upon the condition of the coal when placed in bunkers or holds. W. S. Gould says he knows of no heating after three months unless the coal is disturbed, and the shortest period known to him is five days.

The British report of fires between August 1, 1919, and July 31, 1920, gave the period at which heating was discovered as usually ranging from three weeks to three and one-half months, with the exceptional cases of fire in bunkers within four days and while the vessel was still in port.

During the World War a number of vessels took on small amounts of coal in New York to carry them to Norfolk, where they were to load coal cargoes for South America, but the coal taken on at New York was found to have heated so before the vessels reached Norfolk that it was removed before the new cargo was loaded. An effort was made to attribute many such fires to incendiarism, but the proof was by no means conclusive. Haste in loading, possibly poor coal, and more possibly new coal, may have been the cause of such fires.

Upon land it has been found that 75 per cent of the recorded fires in coal piles occur within three months after the coal has been piled, and that after that time the liability to spontaneous combustion decreases rapidly.[27]

MIXING OF COALS.

A mixture of different coals is generally considered more liable to spontaneous combustion than a uniform cargo of the same coal. No scientific explanation of this can be given and it is a problem that requires detailed study. It is possible that the fine coal that naturally sifts to the bottom of a bunker or cargo may be a point for incipient spontaneous combustion. Marine people generally advise against placing fresh coal upon old coal in a bunker or hold, and all agree in advising that wherever possible all old coal should be carefully cleaned out of a space into which fresh coal is to be placed, and if possible should be used before the fresh coal.

HEATING OF COAL.

DETERIORATION OF COAL DUE TO HEAT.

A distinction should be made between heating and actual spontaneous combustion or burning. Coal may heat without taking fire, and unless the temperature rises to such a degree that the composition of the coal is materially changed through the driving off of a

[27] Stoek, H. H., The storage of bituminous coal: Illinois Experiment Station Circ 6, 1918, 192 pp.

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considerable part of the volatile content, or by the actual burning of a part of the coal, such slow and gradual heating may not materially affect the value of the coal.

METHODS OF DETECTING THE HEATING OF COAL.

The simplest and most generally used test to determine the heating of coal is the distinctive odor that is given off, even when very little heating has occurred. Any such odor should be immediately investigated, the source determined and the coal at that point carefully watched by temperature readings with thermometers placed in tubes driven into the coal. Tubes are sometimes placed in the coal and systematic readings of thermometers placed in the tubes taken and recorded. With cargo coal, and often even with bunkers, such readings may be difficult or impossible to obtain. An iron rod, driven into a mass of coal, pulled out, and tested by being drawn through the hand or along the cheek, is an excellent indicator of heating, particularly if handled by an experienced man.

Many devices have been patented to register the location of fire automatically, but most of them are impractical.

RICH SYSTEM.

The Rich system has been installed on a number of passenger boats and has been awarded a certificate of merit by the Franklin Institute of Philadelphia. Pipes from all parts of the ship where fires are likely to occur lead to a glass detecting cabinet in the pilot house. Exhaust fans draw air through the pipes and into the detecting cabinet and by means of electric lights and reflectors in the lower part of the cabinet a stream of smoke passing into the upper glass section of the cabinet is illuminated and made easily visible. By a system of valves, the pipes carrying the smoke to the cabinet can be shut off from the cabinet and connection made with a steam, carbon dioxide, or other fire-extinguishing medium, which may be forced into the portion of the ship where heating is indicated.

DANGEROUS TEMPERATURES.

What is the dangerous temperature in heating coal? Opinion differs widely as to the temperature at which an effort should be made to reduce the temperature by artificial means and range from 100° to 160° or 200° F.

Coal that reaches 120° on barges in New York harbor is often refused by shipowners. This seems a low temperature, as compared with the usual practice in land storage where no effort need be made to disturb coal until it reaches a temperature of 140 to 150°, and then only if the temperature is increasing rapidly, for if it is increasing

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slowly a temperature of 150 to 160° seems to be safe. The actual temperature at which coal is to be moved or an effort made to get at the point of the fire depends upon the rapidity with which the temperature is increasing, and, more particularly, upon the facilities for handling the coal and getting at the heating spot. On shipboard, it is usually more difficult to move coal, and as it is much less readily accessible than when stored on land and the danger from a fire is much greater, it is undoubtedly advisable to adopt a lower temperature as the danger point than for coal stored under land conditions. W. S. Gould says:

> We advise rejection of coal heated above 100° F., because we have never known coal at that temperature to cool off. From that point the heating progresses relatively fast. Bunker and cargo coal can not be handled like land storage, and higher temperatures on land hold no immediate menace. In case of land storage, coal showing 100° will often cool off by unloading, but I have never seen it happen in cargo or bunker. I believe aboard ship, when coal has heated to 100°, it is a meance that should be taken in hand without delay.

METHODS OF HANDLING HEATING COAL.

Cargo coal can seldom be moved during a voyage, and if the temperature reaches a danger point the only recourse is to turn steam or some inert gas-like carbon dioxide or sulphur dioxide into the hold to shut off air as thoroughly as possible, and go to the nearest port. Bunker coal that has started to heat can often be moved, and either used up at once or cooled off. Water should not be put on heating coal unless the coal is actually afire and all other means have failed.

Several gases that are nonsupporters of combustion have been used to a limited extent for fighting fires instead of steam. These have proved efficient fire-extinguishing agents when a fire is confined. Gases are not as effective as water, however, in absorbing heat and have but little cooling effect on a fire.

CARBON DIOXIDE.

The gas that has been used for this purpose is usually carbon dioxide (CO_2), which may be carried in compressed or liquid form in steel tubes connected to the pipe distribution system.

Lewes[28] recommends placing cylinders of liquid carbon dioxide at points where heating is probable. These cylinders are sealed with a fusible alloy melting at about 93° C., and the valve is opened before the cylinder is placed. When the temperature rises the alloy melts and allows the escape of the gas, which quickly puts an end to oxidation.

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[28] Lewes, V. B., Spontaneous ignition of coal: Jour. Gas Lighting, vol. 94, 1906, pp. 33–34.

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Experiments have recently been carried on to test the effectiveness of an atmosphere of CO_2 to prevent firing of cargo and bunker coal, but the results of these experiments are not now available.

FOAMITE.

W. A. Thomas, engineer, of Chas. Cory & Co., New York City, wrote regarding the use of Foamite for coal fires on ships:[29]

> In regard to the use of Foamite for the extinguishing of bunker and storage coal fires we have not as yet any definite information on this subject. Tests are being conducted, and as soon as results are known we will be glad to advise you.

SULPHUR DIOXIDE.

Sulphur dioxide (SO_2) has also been exploited for the same purpose. In the Clayton system, commercial sulphur is burned in a specially designed furnace connected with the hose by a double line of piping. Air is drawn from the hose through one pipe by a high-powered blower and discharged into the furnace, where it is converted into SO_2, which is then forced back into the hold through the second line of piping. Oxygen is thus replaced by a noncombustion-supporting gas. When the gas contents have reached a certain percentage, the burning sulphur is cut off and the gas-laden air in the hold is circulated by the same machine through a cooler which forms its base, and fresh air is gradually admitted.

So-called fire indicators may be fitted into the machine, with connections to the chart room. In operation, air is drawn from various holds, and any rise in temperature is indicated.

The method is considered objectionable, as SO_2 causes asphyxiation, only 3 per cent of it in the air being fatal to life. It is also injurious to certain kinds of merchandise, as it is a powerful bleaching agent, but in 1914 it was said to have been used on vessels of 2,000,000 gross tonnage.

NITROGEN GAS.

Nitrogen gas has also been tested. It is made by forcing air through a confined burning body where the nitrogen and oxygen of the air are separated, the resultant gases being free nitrogen with some carbon dioxide. As steam vessels are constantly producing and discharging a similar mixture of gases through the smoke stack, an apparatus has been designed to utilize these waste boiler gases for extinguishing fire through the use of a blower with suction attached to the uptake flue over the boiler. A collar made of a coil of pipe, water jacketed, is placed in the suction pipe, so that the gases may

[29] Thomas, W. A., Private communication, August 15, 1922.

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pass freely into the usual pipe distribution system. Funnel gas, however, always contains a large proportion of unburned oxygen, often half as much as ordinary air, and its circulation through heated coal is not to be recommended.

Patent Office records contain many devices for the use of gases for extinguishing fire on shipboard, but most of these are impracticable.

SPRINKLER SYSTEMS.

Sprinkler systems are sometimes used on shipboard, but chiefly for other cargoes than coal. The sprinklers are located near the ceiling and spaced about 10 feet apart. Where the compartment thus protected is not heated in winter, as the hold of the vessel, the pipe system is maintained under air pressure of about 35 pounds, which holds back the water from the sprinkler and thus prevents freezing.

A detailed description of sprinkler systems will be found in a paper by W. O. Teague on "Safety of life from fire at sea."[30]

Instead of an automatic sprinkler system, perforated pipes are sometimes run into cargo spaces through which water may be forced, if necessary. In connection with these perforated pipes there is sometimes also a bell signal attachment in the engine room, the bell being rung at a certain temperature through the medium of a thermostat placed in the hold. This may apply to ordinary cargo spaces, but can not be relied upon to indicate the spontaneous heating of coal, which always commences locally, not generally throughout the mass.

Many naval architects have criticised the application of sprinkler systems to ships, particularly in connection with coal cargoes, on the ground that the systems as used for land buildings have not been sufficiently changed to adapt them to conditions aboard ship. On account of the oily nature of coal and the location of the hot spots beneath the surface of the pile, water from a spray would probably not reach the seat of trouble.

METHODS OF PREVENTING FIRES ON SHIPS.

SUGGESTIONS OF S. D. McCOMB.

S. D. McComb[31] makes the following suggestions for reducing loss by fire on vessels, only that portion being here given that is applicable to coal in ships.

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[30] Teague, W. O., Safety of life from fire at sea: Trans. Soc. Naval Arch. and Marine Eng., vol. 22, 1914, p. 31.

[31] McComb, S. D., Some suggestions for reducing the loss by fire on vessels: Trans. Soc. Naval Arch. and Marine Eng., vol. 18, 1910, p. 191.

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When the sides of a boiler are being covered, the space between the boiler shell and the bunker should not be packed with nonconducting material. Some opening should always be left between the covering and the bunkers to prevent hot ashes from getting between the boiler and the bunker sides.

The care and use of lubricating oil and waste should receive close attention.

Any electric wiring or other installation passing through a bunker or cargo space should be carefully placed.

Stevedores and cargo trimmers should not be permitted to use torches and candles; only closed lanterns or incandescent lights should be used in the hold of the vessel.

Each compartment should be fitted with a pipe running to the pilot house, and air drawn from these pipes continuously. A fire starting in the hold can thus be promptly detected when smoke issues from the pipe.

Each compartment should be fitted with a steam fire extinguisher, so that steam can be turned on immediately if fire is discovered.

Vessels carrying coal should be especially well equipped with fire apparatus. It should be borne in mind that when such apparatus is needed, it is needed badly and quickly; hence it should be tested frequently and so placed that it can be used promptly. An incipient fire is often easily extinguished, but fire gains headway rapidly. Time lost in coupling up a hose may cause the loss of a ship.

All steam vessels should have a steam pump and a hand pump. They should be connected with the same main, the hand pump for use if the steam is not up, or the steam pump out of order. There should never be less than two lengths of hose. The fire main should extend to every deck, and plugs should be located not more than 75 feet apart. In addition to fire extinguishers and hose, sprinklers should be placed between decks.

The following requirements must be complied with before a certificate will be issued for freight steamers:

All boilers, main steam lines, and auxiliary lines carrying boiler pressure, must be thoroughly covered with asbestos or other approved material, and where steam pipes pass through woodwork they are to be fitted with a proper metal collar, or the wood protected in an efficient manner. All woodwork within 6 inches of a boiler at sides, or 12 inches above a boiler or steam dome, or within 2 feet 6 inches of uptakes or breeching, must be covered with sheet-metal-covered asbestos.

Coal bunkers must be cleaned out thoroughly as often as possible, and at least once every 60 days during a season of navigation, making sure that all coal dust and rubbish are removed, especial care to be taken in cleaning shelf space. (This might with advantage be

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interpreted to require bunkers to be always cleaned out before new coal is placed in them.)

Under the head of "Maintenance," the following applies to coal-storage spaces:

Coal bunkers, when located in the hold, shall be cleaned thoroughly when vessels are laid up at the close of season, and no coal left in them. Vessels shall be thoroughly cleaned and no waste or rubbish left on board.

No open lights shall be used on board, excepting the customary torches in engine and boiler rooms, signal lights, and candles when used for trimming cargo.

SUGGESTIONS OF NATIONAL FIRE PROTECTION ASSOCIATION.

In a report of the committee on marine fire hazards to the National Fire Protection Association, Boston, Mass., S. D. McComb, chairman, presented at the annual meeting May 9–11, 1922, the following specific suggestions regarding coal appeared:[32]

ARTICLE IV.—BUNKERS AND HOLDS FOR COAL.

13. *Vents.*—Ventilation of all hold, wing and between-deck bunkers shall be provided for by pipes or trunks leading to the outside atmosphere.

14. *Temperature testing.*—Reserve bunkers and holds shall be provided with sounding trunks, so that internal temperatures may be read as required.

Under the heading of "Appliances," it is recommended that such appliances conform to the national standards of the National Fire Protection Association. These provide in considerable detail for hose and couplings, sprinkler systems, and under the heading of "Steam jets" the method of figuring the size and number of steam smothering pipes is given in detail. Under the head of "Gas" the following item appears:

The use of inert gas, such as carbon dioxide, for extinguishing or preventing fire may be applied to holds, bunkers, and other closed compartments not normally accessible to crew or passengers; but on account of danger to life the use of gas of this character shall be restricted to such spaces. On motor vessels and those equipped with insufficient boiler capacity to permit effective application of steam smothering the installation of a gas system, subject to the foregoing restrictions, is recommended.

Under the head of "Operation," Article III, "Care of coal bunkers," reads:

Care shall be taken that all vents are clear when bunkering is completed. In case of vessels having wooden bunkers using soft coal for fuel, same shall be thoroughly cleaned out at least once every 60 days while vessel is in commission. The coal bunkers of all vessels shall be cleaned on going out of commission or being laid up for over 60 days, making sure that all coal dust and rubbish are removed. Special care shall be taken in cleaning shelf pieces.

[32] National Fire Protection Association, Report of the committee on marine fire hazards: Boston, 1922, 16 pp.

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RULES OF VESSEL FIRE REGISTER (INC).

The rules and requirements of the Vessel Fire Register (Inc.), are essentially the same as those given in the recommendation of Mr. McComb and in the report of the committee on marine fire hazards. The regulations referring to the coal are as follows:[33]

SEC. 5. Where coal or wood, or stores, or cargo of any description, are carried or may be carried alongside of boilers, a partition must be built at least 4 inches clear of boilers, to prevent anything being placed next to the boilers, and under no circumstances may anything be placed between such partitions and the boilers. If anything is or may be carried forward or aft of boilers, similar partitions or bulkheads to be fitted, but these must be at least 2 feet distant from boilers, and space between them and boiler kept clear and clean. A coaming at least 12 inches high must extend from the front of all boilers to side partitions, to prevent coal or ashes getting in.

SEC. 13. The bunkers of all wooden vessels or other vessels having wooden bunkers using soft coal for fuel must be thoroughly cleaned out at least once every 60 days while the vessel is in commission. The coal bunkers of all vessels must be cleaned on going out of commission or laid up for over 60 days, making sure that all coal dust and rubbish are removed, special care to be taken in cleaning shelf piece.

MAINTENANCE.—SEC. 1. Coal bunkers, when located in hold, to be cleaned thoroughly when laid up at close of season, and no coal to be left in bunkers, except for use on board. Vessel to be thoroughly cleaned and no waste or rubbish left on board.

SUGGESTIONS OF H. K. BARR.

In the book "Stowage and dangerous cargo" H. K. Barr[34] says:

Before receiving a cargo of coal, the shifting boards, limbers, sluices, strums, pump wheels, sounding pipe, etc., should be carefully inspected. On steamers especially the sluices should be well oiled, open and shut, and the limbers cleaned out. The cement directly under the sounding rod pipe should be examined, and if damaged repaired. Instances have occurred where from constant use the sounding rod has worked its way through the bottom of the vessel and caused a leak. The side scuttles and ports, if open, should be white leaded shut; all ventilators open and in good working order. Blocking up ventilators to prevent dust coming on deck should never be allowed, as it may lead to a serious disaster sooner or later.

Bunker coal is liable to spontaneous combustion probably in greater degree since the introduction of triple expansion engines and forced draft.

Coal dust will damage most kinds of cargo and the ship may be held liable. It is advisable to wash out and dry all holds after discharging coal before taking in other goods.

The same book describes an explosion on shipboard due to gases escaping from coal, and the instructions of various commissioners illustrate the general lack of knowledge regarding coal and its properties. It was evident that one of the bunkers was not filled with coal and was used as a passageway to a storeroom, and that after this bunker had been closed for some time, someone with a naked lamp

[33] Rules and requirements of the Vessel Fire Register (Inc.), New York, 1915, 22 pp.
[34] Barr, H. K., Stowage and dangerous cargo, 1918, p. 21.

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went into the space and an explosion resulted. In the hearings it was stated that the owners of the collier had not given warning of the necessity for keeping the hatches off, or otherwise ventilating the ship. The master of the ship stated that he could not detect the presence of gas by smell. The wreck commissioner pointed out that an analysis of the coal showed "only so small an amount of sulphur that the gas given off would consequently be comparatively free from smell."

RULES OF UNITED STATES BOARD OF SUPERVISING INSPECTORS.

The general rules prescribed by the United States Board of Supervising Inspectors for ocean and coastwise vessels, which supplement the laws governing the standard inspection service under dates of April 7, 1922, and July 21, 1921, respectively, contain no specific regulations for the handling of coal in bunkers or as cargo, but there are general rules for fires on shipboard, which are given in detail in the above publications. These rules, briefly, provide for the installation of fire buckets, hose, pumps, automatic signaling devices, and a supply of steam or carbonic acid gas or other gas that will extinguish the flame.

HANDBILLS OF BRITISH BOARD OF TRADE.

In July, 1882, the marine department of the British Board of Trade issued the following handbill, No. 50:

It has been represented to the board of trade that some of the recent losses of coal-laden vessels by spontaneous combustion in coal might have been avoided if means had been employed to detect the first indication of heating.

The board, therefore, call the attention of owners, agents, and masters of vessels carrying coal on long voyages, to the fourth recommendation of the royal commissioners, who, in the year 1876, reported on the subject of Spontaneous Combustion of Coal in Ships, which is as follows:

> That when coal is being carried on long voyages, the temperature in the various portions of the cargo should be tested periodically by thermometer, and registered in the log.

Whilst urging on shipmasters and others the importance of attending to the foregoing recommendation with a view of obtaining early information as to the heating of a coal cargo, the board desire to impress upon shipowners, also, the great importance of attending to the recommendations of the royal commissioners which relate to the prevention of spontaneous combustion of coal in ships.

In March, 1907, the British Board of Trade issued the following precaution printed in English, French, German, Italian, and Norwegian:

Masters and officers of ships loading coal at ports in the United Kingdom are warned that accidents have frequently occurred through the ignition of coal gas.

All hatchways should therefore be left open both before and for some time after the cargo is shipped, and as the gas may find its way into fore-

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castles and cabins owing to the bulkheads not being gas tight, a free circulation of air should be provided for in holds and other spaces below deck.

Naked lights should not be taken into, nor matches struck in, these spaces, and it is desirable that, in all cases, a safety lamp should be provided for use on board.

In order to secure adequate surface ventilation, at least two ventilators should be provided for each hold or compartment in which coal is stowed. These ventilators should be of wrought iron or wrought steel, fitted with cowls and placed at opposite ends of the compartment or as far apart as circumstances will permit.

In the event of adequate ventilation not being provided the vessel will be liable to be detained.

Any further information required on the subject of ventilation may be obtained on application to the officers of the Board of Trade.

OFFICIAL NOTICES, GREAT BRITAIN.

In the Official Notices for 1912, issued in Great Britain, Notice 11, Coal Cargoes, was as follows:

The attention of the master is directed to the following recommendations of the royal commission appointed to inquire into the causes of spontaneous combustion of coal on board ship:

2. That the breakage of coal in its transport from the pit to the ship's hold, the shipment of pyritic coal in a wet condition, and especially ventilation through the body of coal cargoes, conduce to spontaneous combustion, even though the coal may not be unfit for conveyance on long voyages.

4. That when coal is being carried on long voyages the temperature in the various portions of the cargo should be tested periodically by thermometer, and registered in the log.

5. That with a view to guard against explosion, free and continuous egress to the open air independently of the hatchways should be provided for the explosive gases by means of a system of surface ventilation, which would be effective in all circumstances of weather.

In the event of an inquiry into any casualty arising on board this ship from spontaneous combustion or explosion, any neglect on the part of the master or officers of these recommendations will be brought to the notice of the court.

The master is also warned that in the event of his vessel being found to be in a state dangerous to human life, either from through ventilation, which is conducive to spontaneous combustion of the coal, or from not having sufficient surface ventilation to carry off explosive gas, he will render the ship liable to detention for unseaworthiness, and himself and the owners liable to prosecution for taking the vessel to sea in an unseaworthy condition.

Masters and owners of ships carrying coal are also warned that gas from the hold or 'tween decks may find its way into the forecastle and cabins if the bulkheads are not gas-tight. Persons in charge of coal-laden ships should bear in mind the dangers resulting therefrom, and the consequent impropriety of introducing naked lights in these places.

RECOMMENDATIONS IN LLOYD'S REGISTER.

The report of the chief engineer surveyor of Lloyd's Register of Shipping in 1912 included certain recommendations, quoted in full on pages 21 and 22.

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MEMORANDUM OF BRITISH BOARD OF TRADE.

In the Memorandum of the British Board of Trade, dated 1920, relating to the carriage of dangerous goods and explosives in ships, there are no specific regulations as to the carriage of coal, but dangerous goods are defined as:

All substances of an inflammable nature which are liable to spontaneous combustion, either in themselves or when stowed adjacent to other substances, and also which, when mixed with air, are liable to generate explosive gases, or gases which produce suffocation or poisoning or the tainting of foodstuffs.

Dangerous goods should be stowed in well-ventilated compartments as far as possible from engine and boiler room bulkheads and from living quarters, and these compartments should be separated off by efficient bulkheads. The goods should be stowed adjacent to or in the hatchway in such a manner as to be always accessible.

Particular care should be taken when more than one kind of dangerous or inflammable goods is carried in the same ship, or when dangerous goods are carried in a ship carrying coal as cargo. They should not be stowed in compartments below passenger spaces or compartments opening out into such spaces.

No explosive should be carried in a hold containing coal, nor in a 'tween-decks over a hold containing coal, except safety cartridges, safety fuse, percussion caps, and fog signals, unless especially authorized by the marine department of the board of trade.

Sulphuric acid can be carried with safety under deck, if a layer of slack coal not less than 1 foot in depth is laid at the bottom of the hold and carefully leveled off. Then a tier of drums should be stowed upon it, and when the first tier is completed additional coal should be added and leveled off. (Slack coal, known as breeze, smithies, small's, or such trade types of coal, can be used for this purpose.) A further tier of drums can then be laid and the process of filling in with the small coal again resorted to, and so on to a height of as many as four tiers.

In the event of leakage, coal even in a powdered state will not evolve heat by reason of the presence of sulphuric acid, and the marketable condition of only so much of the coal as is wetted by the sulphuric acid is affected.

The possible results that may be anticipated as regards spontaneous combustion in a cargo of coal on the surface of which drums of sulphuric acid have been imbedded, are:

First: If the sulphuric acid escapes into the coal, spontaneous combustion will not take place within the region of the leakage.

Second: If spontaneous combustion takes place first, then the rupture of the drums and consequent escape of the sulphuric acid will retard or extinguish the fire by the production of sulphurous-acid vapor, in which combustion can not be sustained. This gas has a pungent odor and a strongly suffocating effect, so that great care should be taken to keep away from it.

Any coal that has been wetted with sulphuric acid should not afterwards be used.

SUMMARY OF SUGGESTIONS AND RECOMMENDATIONS REGARDING THE PLACING AND HANDLING OF COAL FOR CARGO AND BUNKER PURPOSES.

1. The danger of loss of life or of a total loss or damage to vessels from coal carried in bunkers or as cargo is sufficient to require great care in choosing, handling, and watching coal placed on ships.

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2. Information is lacking on the spontaneous combustion of coal on ships, and it is very desirable that accurate data be gathered and studied for the benefit of the shipping industry.

3. Many kinds of bituminous coal have been transported on ships without spontaneous combustion developing; on the other hand, spontaneous combustion probably has developed in all varieties of bituminous coal carried on ships. There is undoubtedly a difference in liability to spontaneous combustion with different coals, but the data available at this time do not permit a classification of coal to be made upon this basis. Hence, when a choice is possible, a coal that, as shown by its past record, is particularly liable to spontaneous combustion should not be put on a ship. If the choice is possible, and coal with a bad history must be used, especial care should be taken in stowing and watching it.

4. As spontaneous combustion is mainly due to the oxidation of fine coal, liability to spontaneous combustion is greatly reduced if fine coal and dust can be removed by screening, but this is usually not practicable with present coaling methods and because run-of-mine coal is generally furnished to ships, particularly at American ports, both for cargo and bunker purposes. This requires that extra precautions be taken. The least friable of the coals available should be chosen, if possible, and care used in handling the coal to minimize breakage and crushing.

5. Although it is known that sulphur in coal in the form of pyrites is not the chief cause of spontaneous combustion, as was formerly supposed (and still held to be the case by many), pyritic sulphur may be a contributing cause, due to the heat produced in its oxidation and the fact that the oxidation of the pyrites breaks up the lumps of coal. It is wise, therefore, to select a low-sulphur coal, if possible; but it must not be taken for granted that a low-sulphur coal will be free from spontaneous combustion. It should also be remembered that a considerable amount of the total sulphur as shown by the ordinary chemical analysis may be organic sulphur which, so far as is now known, has no effect on spontaneous combustion.

6. The evidence in regard to the chemical action of moisture in coal in aiding or retarding spontaneous combustion is very contradictory, although experiments in France and New South Wales show that coal thoroughly drenched with water when placed in a bin did not heat, whereas similar coal similarly placed in a bin dry heated quickly. As vessels must usually be coaled promptly no attention can be paid the weather conditions, and it seems to make little difference as to the tendency to fire whether coal is loaded in wet or in dry weather.

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7. Practice and opinions vary widely in regard to the ventilation of bunkers and holds. Many advocate keeping the coal spaces as nearly air tight as possible by battering down the hatches, but others advocate taking off the hatch covers, when weather conditions permit, to provide surface ventilation. Adequate ventilation throughout a coal cargo by pipes or by ventilating chimneys of coarse coal through the pile as is advocated by some is impracticable, and it seems better to distribute the coal uniformly and to prevent as far as possible segregation of the sizes, as such segregation tends to set up air currents throughout the mass of the coal. Moist air circulating through a coal pile seems to lower its temperature of ignition. Ventilating funnels should be provided in connection with bunkers and holds to carry off the explosive gases given off by many coals, and great care should be observed in opening a bunker or hold that has been tightly closed to test for explosive gases. Open lights should be prohibited in closed spaces where coal is stored.

8. When coal is loaded trim it, if possible, in horizontal layers to avoid separation of the sizes, rather than dump it on a cone and thus permit large lumps to roll to the bottom of the cone and the fine coal to collect near the top of the pile, just under the hatches, where fires are often known to start.

9. Thoroughly clean out bunkers and holds before fresh coal is put in, and closely inspect coal as it is being loaded, removing from it any waste or pieces of wood, paper, or similar combustible material which may assist spontaneous combustion.

10. The mixture of different kinds of coal, or the placing of fresh coal on old coal that has been in the bunker for some time is generally considered unwise. Although there is no scientific explanation for this, in the absence of evidence to the contrary it is wise not to mix coals if mixing can be avoided. Many advocate using the coal in the order in which it has been placed on shipboard, although this is contrary to the experience in land storage—that coal gradually seasons and becomes less liable to spontaneous combustion.

11. Keep the coal as cool as possible, and avoid placing it in contact with outside sources of heat, such as steam pipes and hot-air ducts. Protect bunkers from the heat of boilers and engines.

12. Take the temperature of the coal at regular intervals, the oftener the better, if there is any tendency to heat. If the temperature reaches 100° F. and is rising rapidly, move the coal to cool it off by contact with air, steam, or, in extreme cases, water. If water is used, burn the coal as soon as possible and keep it separate from the other coal, as the application of water to hot coal breaks it up and by thus exposing fresh surfaces renders it more liable to spontaneous combustion.

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13. Provide an edequate steam supply, hose, pumps, and other fire-fighting equipment, and always keep them ready for use.

14. Some automatic fire-detecting apparatus in the pilot house or engine room is advisable.

15. Provide for the egress before men enter places where coal is kept, of explosive and other gases that are given off by coal, and avoid open lights in cargo and bunker spaces. Clean the vents leading from bunker or cargo spaces after coal has been put in place.

16. Clean out thoroughly, when the ship goes out of commission, all spaces where coal has been kept, as fine coal left in corners and on ledges frequently fires.

17. Do not run electric wiring, unless in metal conduits, through spaces in which coal is placed. Use every precaution to prevent sparking at electric contacts.

FUTURE INVESTIGATIONS.

The Bureau of Mines cordially invites the cooperation of all connected with the shipping industry in obtaining more specific information concerning coal taken on ships, either in bunkers or as cargo.

In order that the information obtained from different sources may be compared and studied to the best advantage, the following list of questions has been prepared. This list undoubtedly contains some questions that can not be answered from the records kept by most ships, but an effort has been made to include all items that should enter into a comprehensive study of the subject.

Any one having data that bear on any of the questions is urged to fill in the accompanying blanks and forward them to the Bureau of Mines. If additional blanks are needed they will be supplied by the Bureau of Mines, Washington, D. C.

QUESTIONNAIRE ON BUNKER AND CARGO COAL.

U. S. Bureau of Mines.

WASHINGTON, D. C.

1. Information furnished by _____. Date _____.
   Official position _____. Company _____.
   Mailing address _____.
2. Name of ship _____. Character of ship _____.
   Port of loading _____. Date of loading _____.
3. Coal loaded:
   Kind, _____; trade name, _____; where mined, _____.
   Size, _____; screened, _____. Company furnishing coal, _____.

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3. Coal loaded—Continued.

Analysis of coal: Moisture, _____; volatile, _____; fixed carbon, _____; ash, _____; sulphur, _____.

NOTE.—If several kinds of coal were loaded, give an analysis of each on back of sheet.

Was more than one kind loaded? _____.

Were different kinds mixed in loading? _____.

Was one kind placed on top of the other? _____.

Was coal damp when loaded? _____.

Weather conditions when coal was loaded: Temperature, dry or moist? _____.

Was coal inspected during loading and waste, pieces of wood, etc., removed? _____.

4. Method of loading:

Was coal loaded into bunkers?_____; cargo?_____; or at coal piers? _____

Was coal loaded from cars?_____; barges?_____; stock pile? _____.

How long was coal in barge (or car) before loading?_____.

If loaded from stock pile, how long had coal been in storage?_____.

How long had coal been mined?_____.

Were bunkers or holds cleaned out before coal was loaded into them? _____.

If not, how much coal was left?_____ Kind of coal left?_____.

What appliances were used to load coal?_____

Was coal dumped into ship so as to form a cone and so that the sizes would thus separate?_____.

Was coal trimmed in horizontal layers to prevent separation of sizes? _____.

Was coal trimmed by hand?_____. By mechanical trimmers? _____.

Was coal wet down during loading?_____. If so, to what extent? _____.

Amount of coal loaded, tons_____. Depth of coal in hold_____.

Cargo capacity?_____. Bunker capacity?_____

5. Handling of coal after loading:

Were hatches kept on during voyage?_____.

Were hatches removed to ventilate holds during voyage?_____.

How were coal spaces ventilated other than through the hatches? _____.

Was temperature of coal taken?_____. How?_____.

How often?_____? How recorded?_____.

Highest temperature noted?_____. How soon after loading was rise of temperature?_____.

Did temperature rise slowly?_____. Or rapidly?_____.

Did coal actually fire?_____. Did an explosion take place? _____.

If so, what was the probable cause?_____.

What method was used to lower temperature of coal when heating was discovered? _____.

What precautions were taken to prevent heating?_____.

What was the cause of the heating?_____.

What evidence was there to support this opinion?_____.

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5. Handling of coal after loading—Continued.

To what extent and how was coal cargo damaged?_____.

To what extent and how was ship or other cargo damaged?_____

_____.

What measures would you suggest to prevent heating of coal?_____.

What measures would you suggest to fight heating that has already started?_____.

If in bunkers, location of bunker?_____. As regards boilers and steam pipes?_____.

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PUBLICATIONS ON THE STORAGE OF COAL.

A bibliography of the literature on the storage of coal can be obtained from the Engineering Experiment Station of the University of Illinois, Urbana, Ill.

A limited supply of the following publications of the Bureau of Mines has been printed. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, upon payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 136. The deterioration of stored coal, by H. C. Porter and F. K. Ovitz. 1917. 38 pp., 7 pls.

TECHNICAL PAPER 170. The diffusion of oxygen through stored coal, by S. H. Katz. 1917. 49 pp., 1 pl., 27 figs.

TECHNICAL PAPER 235. Safe storage of coal, by H. H. Stoek, 1920, 10 pp.

TECHNICAL PAPER 311. Factors in the spontaneous combustion of coal, by O. P. Hood. 1922. 9 pp., 8 figs.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl., 9 figs. 10 cents.

BULLETIN 29. The effect of oxygen in coal, by David White. 1911. 80 pp., 3 pls. 20 cents.

TECHNICAL PAPER 16. Deterioration and spontaneous heating of coal in storage, by H. C. Porter and F. K. Ovitz. 1912. 14 pp. 5 cents.

TECHNICAL PAPER 65. A study of the oxidation of coal, by H. C. Porter. 1914. 30 pp., 12 figs. 5 cents.

TECHNICAL PAPER 98. Effect of low-temperature oxidation on the hydrogen in coal and the change of weight of coal in drying, by S. H. Katz and H. C. Porter. 1917. 16 pp., 1 pl., 8 figs. 5 cents.

TECHNICAL PAPER 172. Effects of moisture on the spontaneous heating of stored coal, by S. H. Katz, and H. C. Porter. 1917. 25 pp., 1 pl., 8 figs. 5 cents.

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